# **The D-Box:** a hackable digital musical instrument

Assembly guide, rev. 1.0
14 July 2016

**Introduction**

Musicians often use instruments in unexpected ways. This is so common that many instruments are primarily associated with performance techniques which were not part of the original design, for example jazz saxophone pitch bends, distortion on the electric guitar, and scratch DJ use of the turntable. Some performers even make physical modifications to their instruments to adapt them to their personal needs.

The D-Box is a digital musical instrument designed to be played in idiosyncratic and unexpected ways. Inspired by the practice of *circuit bending* (improvisatory rewiring of electronic devices), the D-Box allows the performer to change the behaviour of the instrument by manipulating a breadboard of electronic components inside. The sound of the instrument is controlled by a combination of the components on the breadboard and the software running on Bela inside.

The D-Box is built as a 15cm wooden cube containing a speaker, battery and Bela. Two touch sensors on the top of the box are the main playing controls of the instrument. The touch sensor near the back of the instrument (further from the speaker) controls the pitch of the sound; the touch sensor at the front acts as a bandpass filter on that sound. Both sensors respond to the position of the finger along their long axis. The pitch sensor also contains force-sensing resistors (pressure sensors) underneath, so that pressing harder on the sensor increases the volume of the sound.

The side panels of the D-Box are designed to be removable. Opening one side panel will reveal a breadboard (referred to in some D-Box documentation as the *matrix*) which is pre-populated with some simple analog circuits. Changing these circuits will alter the behaviour of the instrument, often in glitchy and surprising (though never random) ways. The circuits on the breadboard are protected from damage, such that anything can be connected together without risk of damaging the instrument. A separate guide is available explaining the function of the circuits on the matrix.

**About This Guide**

This document is an assembly guide for the D-Box. It assumes that you have a kit of materials (such as those distributed through the Bela Kickstarter campaign) which includes pre-cut wooden enclosure pieces, pre-assembled cables and other parts. This guide explains the steps needed to build a D-Box from these materials.

No soldering is required to build the D-Box from a kit. Building the instrument will take several hours of active work, plus a few more hours of time for glue to dry in the early steps.

It may be helpful to read this guide in its entirety before starting the D-Box build, so you can see how the steps relate to one another.

## Materials

The following materials are provided in the D-Box kit:

*Electronics:*

- BeagleBone Black
- Bela cape for BeagleBone black
- 8GB SD card with Bela image preloaded
- 2x capacitive touch sensors
- 2 force-sensing resistors (0.5" round, with long leads pre-soldered)
- 2 piezo discs, with a 3-pin Molex connector attached
- Blue LED with resistor and wires pre-soldered
- Speaker [Visaton FR10HM] with wires pre-soldered
- Rechargeable battery
- Solderless breadboard
- Small parts for breadboard:
  - 2x 33k resistors
  - 1x 27k resistor
  - 1x 22k resistor
  - 1x 18k resistor
  - 1x 180k resistor
  - 2x 0.1uF capacitors
  - 2x potentiometers

Cables:

- USB mini-B cable (for connecting BeagleBone Black to computer)
- USB micro-B cable (for charging battery)
- USB to round barrel cable (for powering BeagleBone Black from battery)
- 2x audio adapter cables: 3-pin Molex connectors to 3.5mm stereo jacks
- I2C Y-cable for touch sensors: 4-pin Molex connector to two 6-pin sockets
- 20-pin wire ribbon with breadboard wires on each end
- 2-wire pin-to-socket ribbon for use with the speaker
- Bundle of jumper wires

*Mechanical parts:*

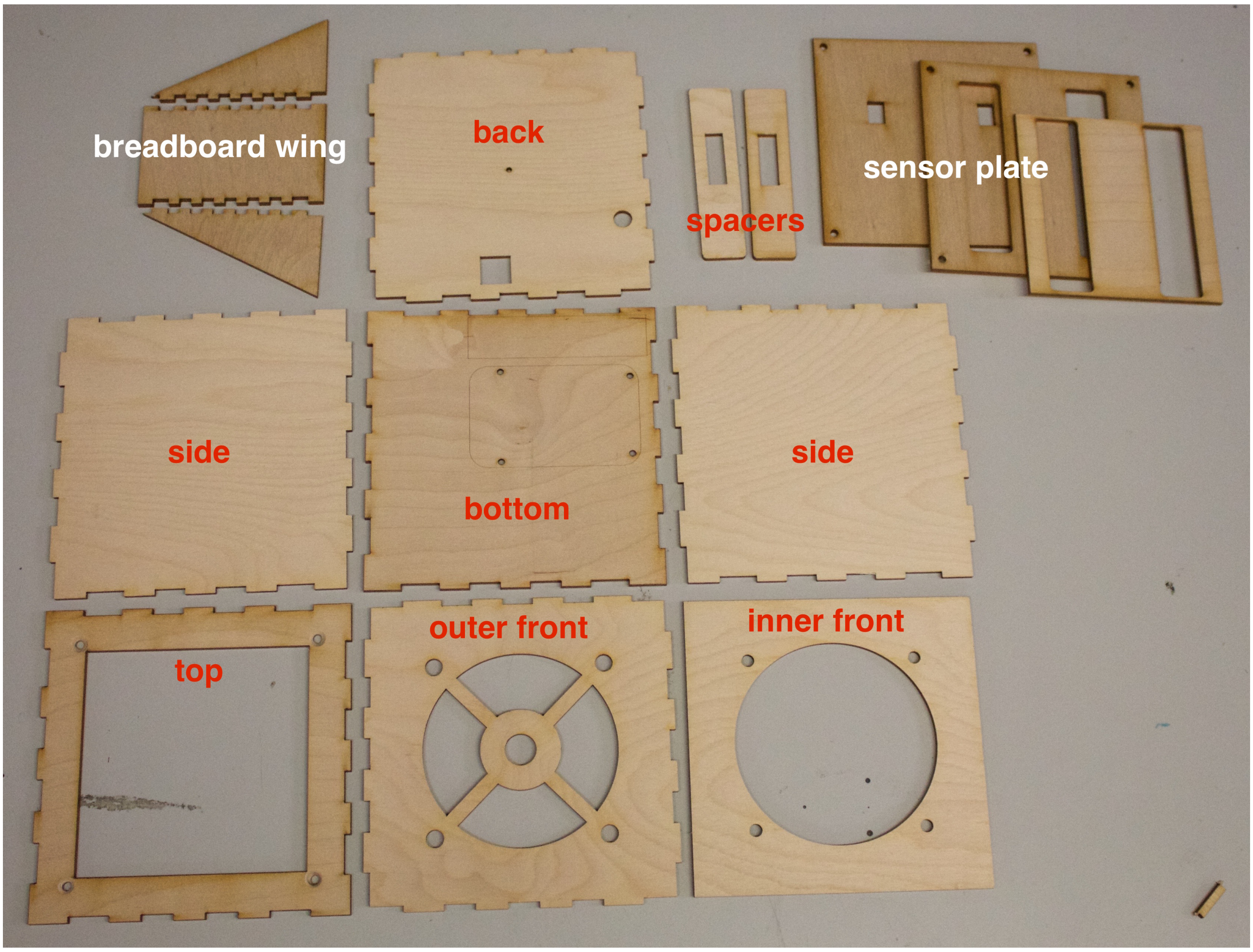
- Case, laser cut from 3mm thick plywood
- 6x cardboard spacers (for assembling top sensor panel)
- 1 mounting plate for headphone jack, made from printed circuit board
- 2x velcro strips
- 1 piece of double-sided foam tape
- 1 piece of adhesive putty ("Blu-tak")
- M3 hardware: 4 flat head screws, 4 pan head screws, 4 hex spacers
- M4 hardware: 4 flat head screws, 4 pan head screws, 8 nuts, 4 washers, 4 lock washers
- 1 bottle of wood glue
- 1 packet of superglue

## Tools

Beyond the materials provided in the kit, the following tools are needed to assemble the D-Box:

- Phillips screwdriver
- Scissors
- Optionally, a hot glue gun (as an alternative to the provided superglue)

## Part 1: assemble the outer case

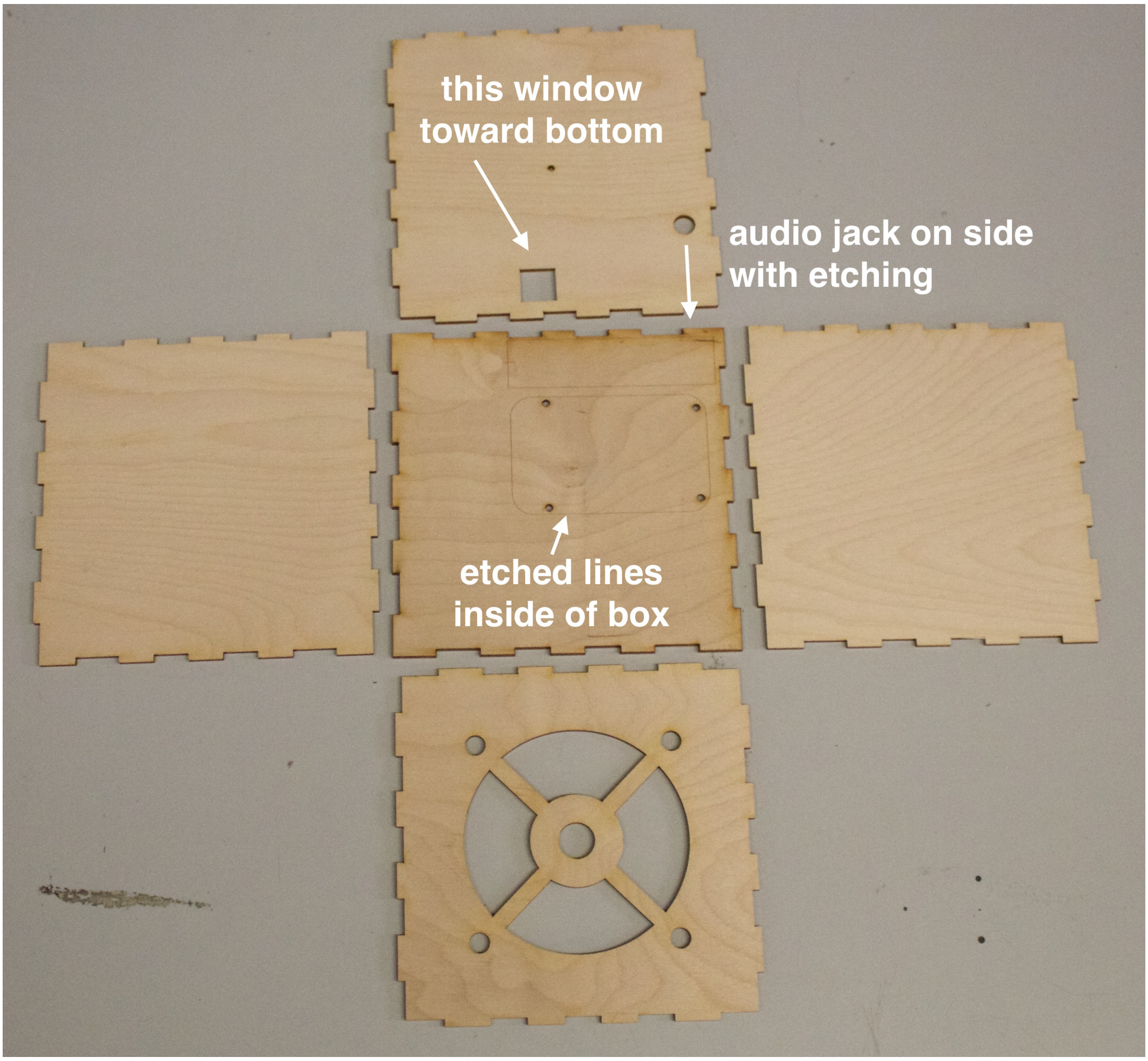



The case is made from a set of laser-cut pieces with interlocking tabs to hold it together. It will hold loosely together using only the friction of the tabs, but wood glue is used to hold it permanently and strongly together.

The case consists 15 wooden pieces:

- **Top** (with tabs and large square cutout internally)
- **Outer front** (with tabs and cutout for speaker)
- **Inner front** piece (without tabs, round cutout for speaker, smaller than outer front)
- **Bottom** (with tabs and 4 holes and laser engraving for BeagleBone Black)
- **Back** (with tabs and 3 holes: LED in centre, square hole for battery switch, round hole for audio jack)
- **2 sides** (tabs around edges, no cutouts)
- **Sensor plate - top** (square piece without tabs or mounting holes, two long cutouts for the touch sensors)
- **Sensor plate - middle** (square piece without tabs but with mounting holes on corners and two long cutouts for the touch sensors)
- **Sensor plate - bottom** (square piece without tabs but with mounting holes on corners; two small square cutouts for touch sensor *cables*)
- **3 breadboard wing pieces** (smaller rectangular piece with tabs on 2 sides, plus two triangular pieces which attach to it; used to hold the breadboard inside the instrument)
- **2 touch sensor spacers** (long, narrow wooden pieces with rounded corners, same outline as the touch sensors)

**Preparation**

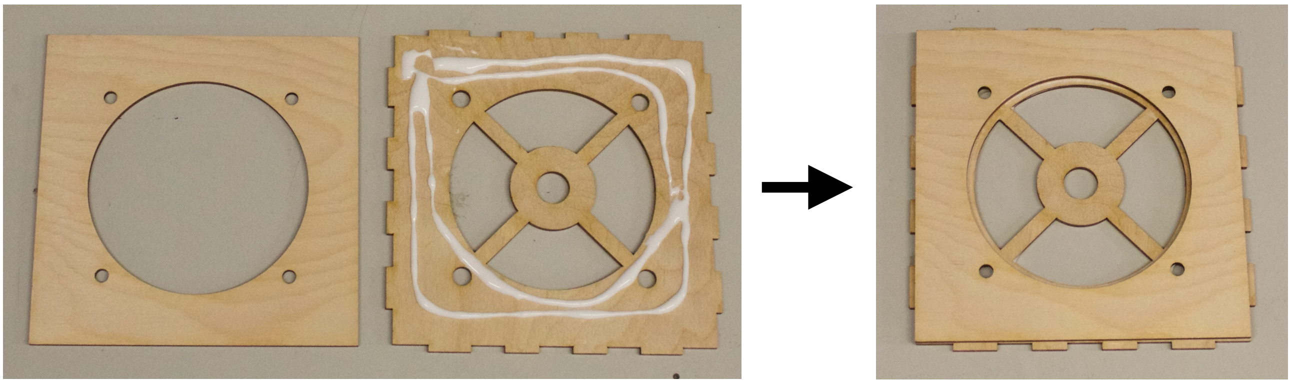



*(Not shown: top panel and inner front panel)*

First, lay out the outer pieces of the case to get a sense of how the box fits together. Notice that for the bottom piece, the laser etched lines should face toward the *inside* of the case. Also notice the orientation of the back piece: the rectangular window faces *down* toward the bottom plate, and the round hole for the audio jack is on the *same* side as the mounting holes for the BeagleBone Black.

Try assembling the case **without glue** to make sure you understand which piece goes where. Once the case is glued together, it cannot be taken apart again.

## Glue front speaker plate

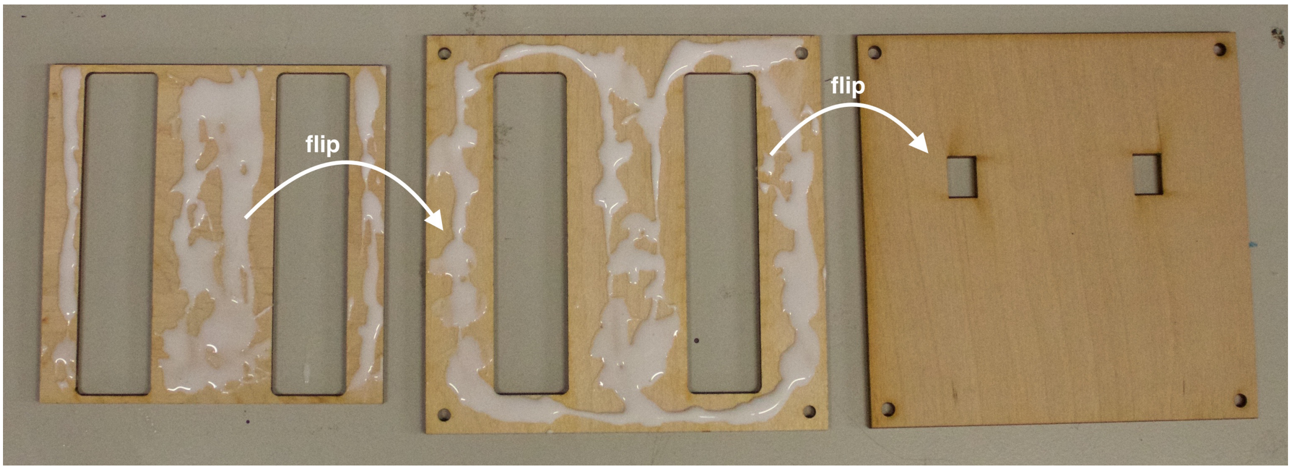


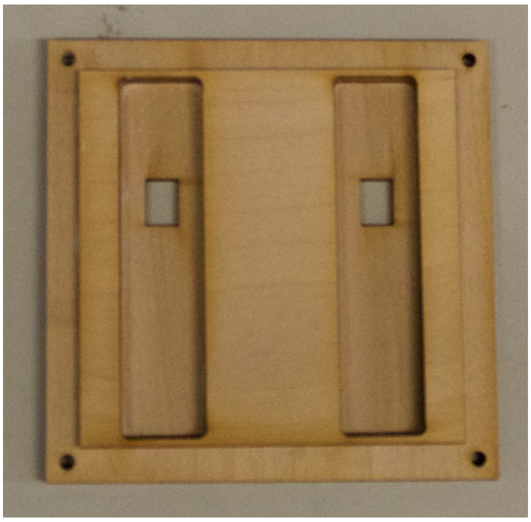
The **outer front** and **inner front** plates need to be laminated to one another. Spread a thin layer of wood glue on one piece or the other, and press the two plates together. (Too much glue isn't helpful: it will squeeze out the sides and make the pieces less likely to stick closely together.)

**Important:** make sure the pieces are exactly aligned on each side. The **inner front** plate should line up exactly without the spaces between the tabs on the **outer front** plate.

Once you have glued the pieces together, place them under a heavy flat object to dry for at least 3 hours.

## Glue sensor plate



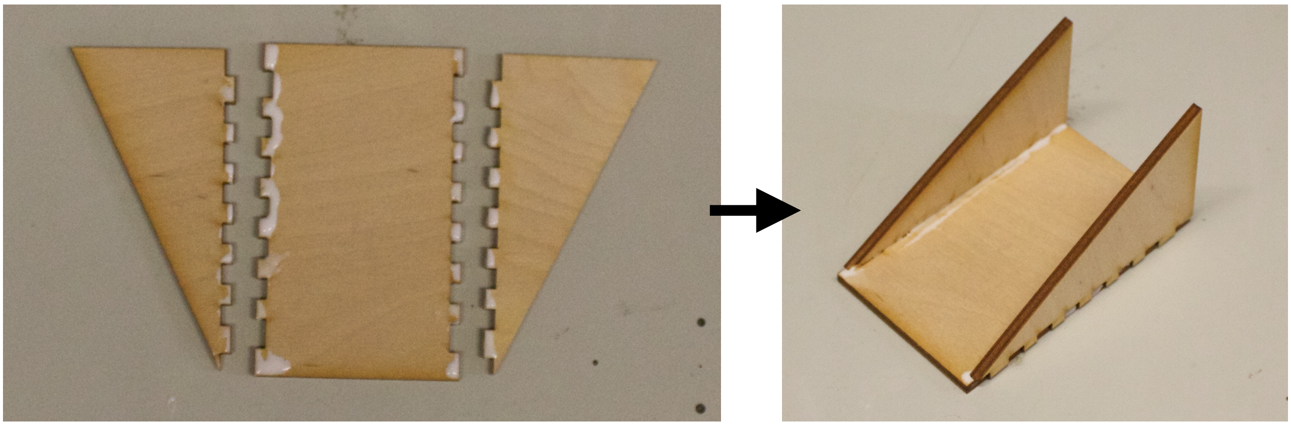
The three pieces of the sensor plate need to be laminated to one another. Spread a thin layer of glue on the **top sensor plate** and the **middle sensor plate** and press the three sheets together.

**Important note 1:** make sure the holes in the plates line up exactly. The screw holes should line up exactly between the **middle** and **bottom sensor plates**. The rectangular holes in the **bottom sensor plate** should also be visible within the long cut-out sensor trays of the **top** and **middle** plates. Also make sure the edges of the sensor cutouts line up *exactly* between the **top** and **middle** plates. (If these three plates are not precisely aligned, it will be hard to fit the sensors in later.) Once you have glued them, place them under a heavy flat object.

**Important note 2:** after pressing them together, clear away any excess glue that has squeezed out. This will be easier to do before the glue dries. Excess glue can make it hard to fit the touch sensors and mounting screws later on.

After clearing the excess glue, keep the pieces under a heavy object and leave to dry for at least 3 hours. (Be careful not to slide the heavy object on top or it may disrupt the alignment of the plates.)

**Glue breadboard wing**

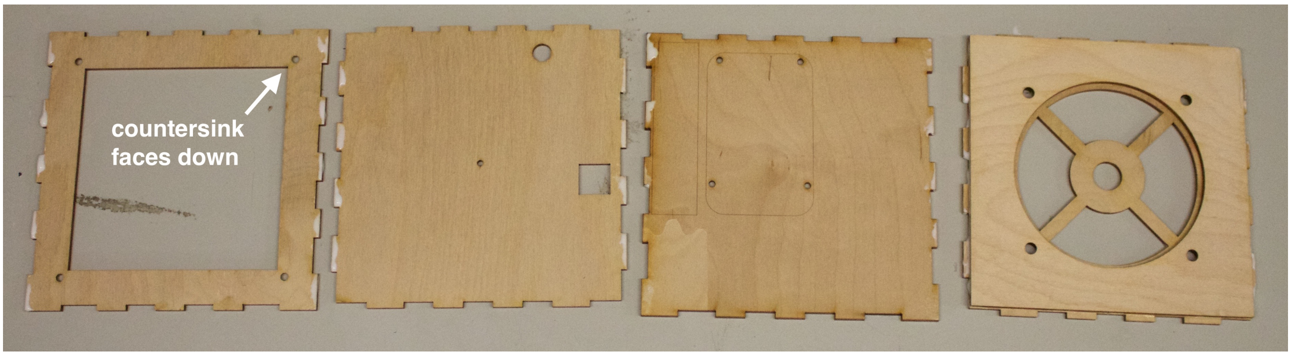


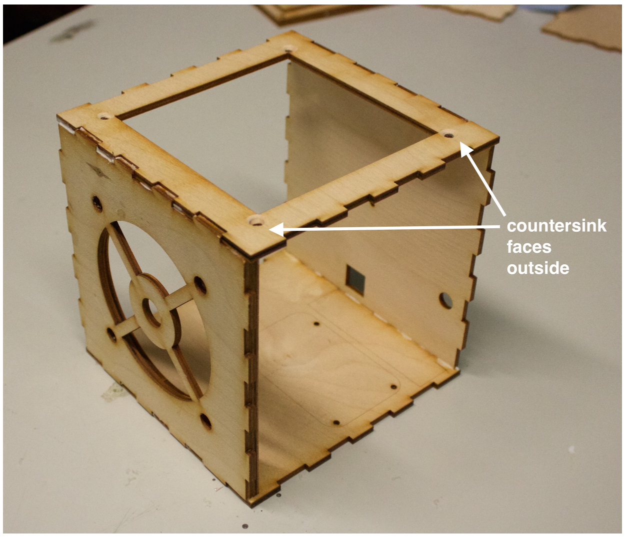
Put a thin layer of wood glue on the tabs of all three **breadboard wing** pieces, then fit the triangular pieces into the rectangular piece at right angles. Make sure the tabs interlock as fully as possible, and wipe away any excess glue.

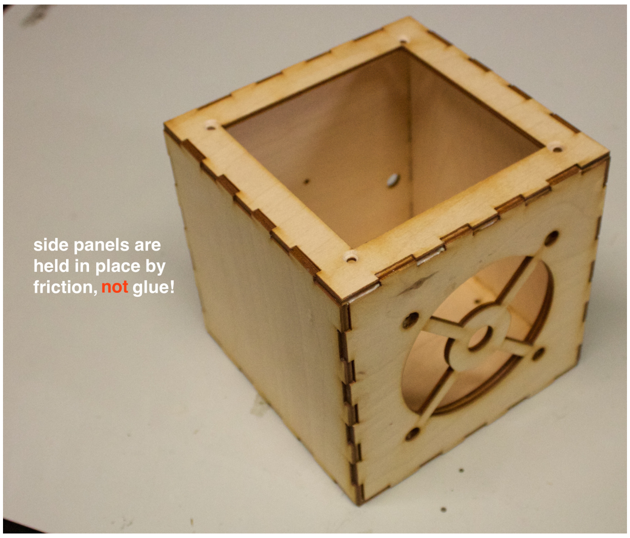
**Tip:** Once you put the pieces together, use a square or other rectangular object to check if the triangular pieces are standing exactly vertically.

Once you have assembled the pieces, leave them to dry for at least 3 hours.

**Glue outer case**




Four of the six outer case pieces will be held together with wood glue. (The side panels will not be glued as these are designed to be removable.)

Line up the **top, front, bottom** and **back plates** as shown in the image. The **inner speaker plate** (i.e. the smaller of the two plates) should be facing upwards, and the laser etchings on the bottom plate should also be facing upwards. Make sure the orientation of the cutout holes in the **bottom** and **back** plates matches the image.

Also note that the screw holes in **top plate** are *countersunk* (cut at 45 degree angles) on one side. The countersunk side should be facing *down* toward the desk.

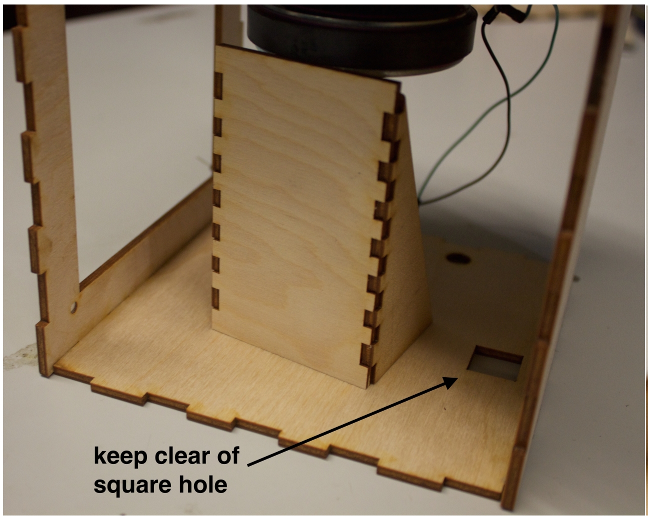
Once you have the pieces laid out correctly, apply a thin layer of glue on the tabs which connect the pieces together, as shown in the image. Assemble the box, making sure the tabs fully interlock. Excess glue that goes inside the box can be spread along the joints with a finger; excess glue that gets into the side panel tabs should be wiped away.

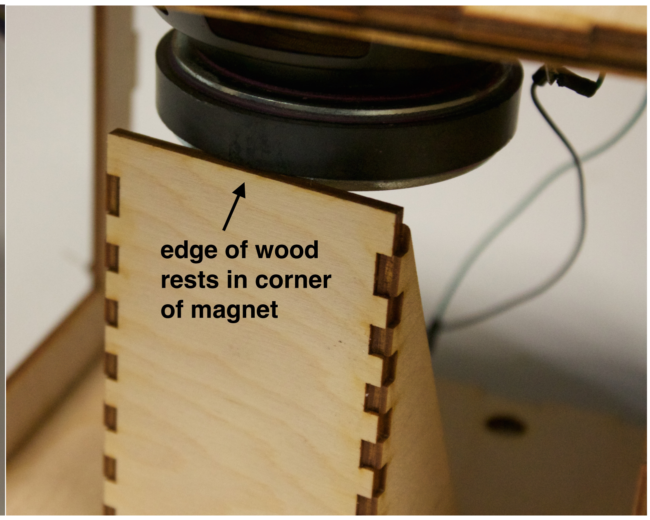
*Before the glue dries,* add the **side panels** (without glue) to hold the entire cube together. It's important to have the side panels in place as the box dries, to keep the pieces at the right angle. This will ensure you can get the side panels on and off later.
Leave the box to dry for at least 3 hours, at which point the side panels can be removed.

**Attach the speaker**

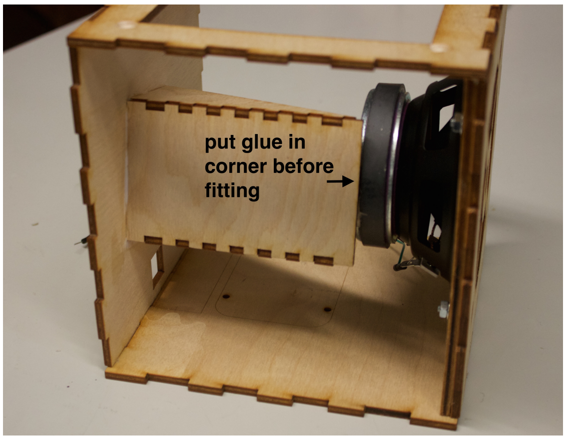
The **speaker** attaches inside the box, secured using the **M4 hardware**. One **pan head screw** should be inserted from the front of the box into each of the four mounting holes. Secure each corner of the speaker with a **lock washer**, a **regular washer** and then a **nut** (in that order). The terminals of the speaker should face the *bottom* of the box.

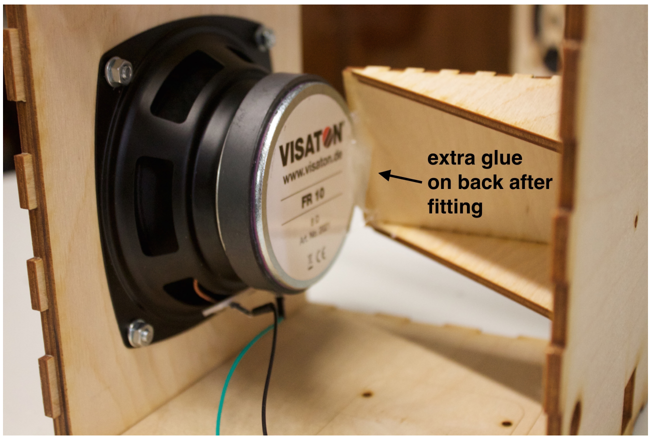
## Glue the breadboard wing into the box




The **breadboard wing** should sit in the middle of the inside of the box, tilted slightly upward for easy access to the breadboard. Looking at the box from the front, the flat part should face to the *left* side, the opposite direction from the screw holes in the bottom plate. The length of the wing is designed to fit neatly into the corner of the speaker magnet (see second image). Before applying glue, place the wing inside the box to check its position. This is easiest to do with the box turned so the speaker faces upward.



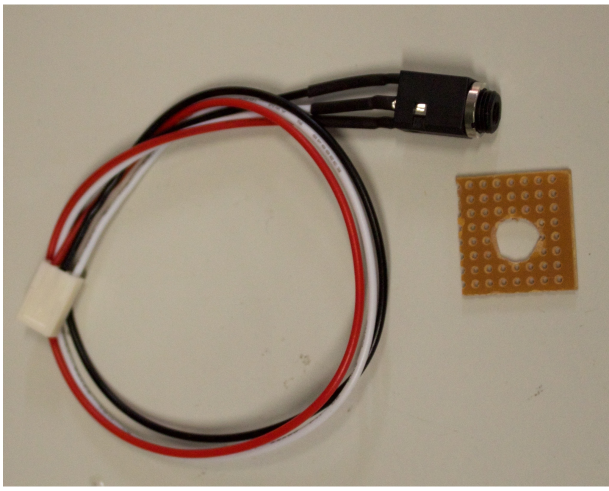

After verifying the location and fit, add wood glue to the sides of the wing which touch the **back plate** of the box.

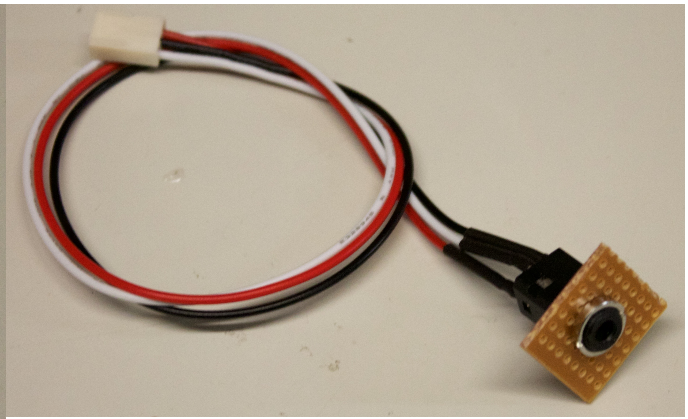
The side which faces the speaker can be secured in place using hot glue (if available) or the included superglue. Before inserting the wing into the box, put a small amount of glue on the speaker magnet where it will touch the plate. Then insert the wing and adjust it to the right height and angle.

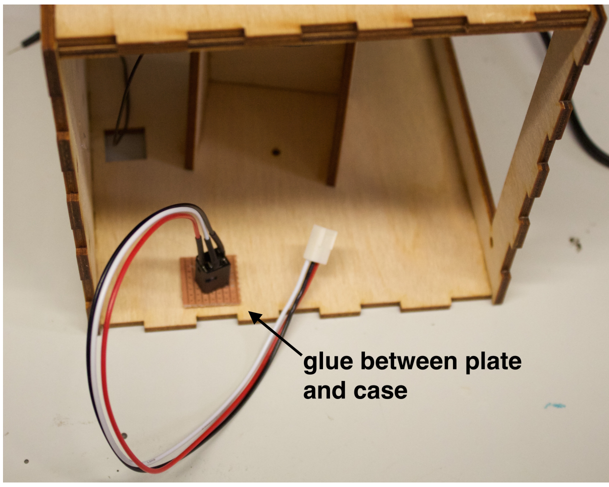
**Important:** make sure the wing is at least 0.5cm clear of the square hole in the back plate. This is where the battery will fit, and it's important that the battery is able to fit underneath the wing. Also make sure the back part of the wing does not cover the LED hole.

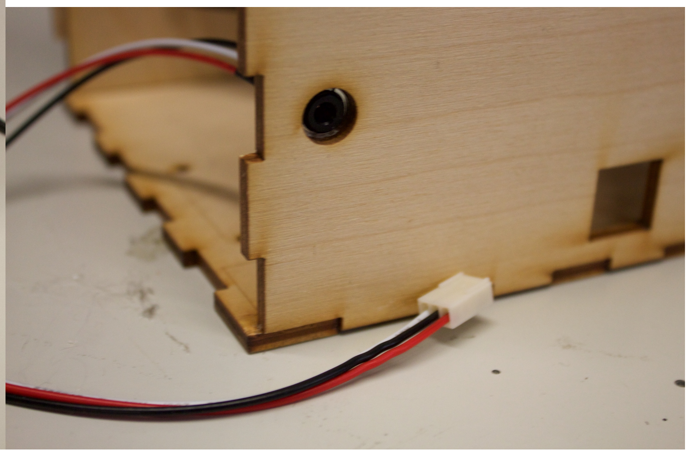
Once installed, the wing can be further secured to the speaker with extra glue applied from the back. Leave the glue to dry for at least 3 hours. At this point, the box should feel quite sturdy, even without the side panels installed, because the wing and speaker should collectively provide some extra rigidity inside the box.

## Install headphone jack







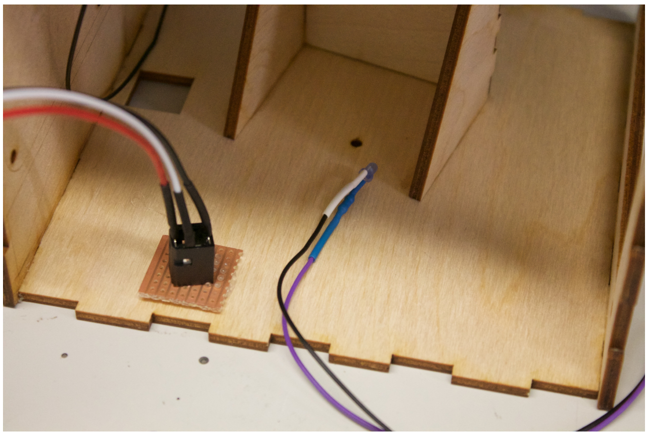
Take one of the two **audio adapter cables**, remove the metal nut and attach it to the **mounting plate** which is made from a piece of perforated circuit board. (This plate is needed because the wood is too thick to attach the jack directly.)

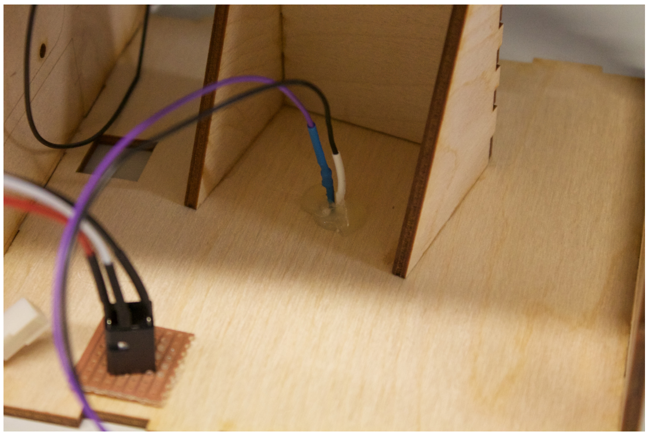
Next, using superglue or hot glue, secure the mounting plate to the **back plate** of the case, such that the headphone jack appears through the round hole. It may be a fairly tight fit.

**Important:** make sure that no glue gets inside the audio jack itself, and that the mounting plate does not extend beyond the edge of the wooden tabs, or the side panel will not fit on later.

**Note:** the second audio adapter cable is not needed for the D-Box, but it can be used for other Bela projects.

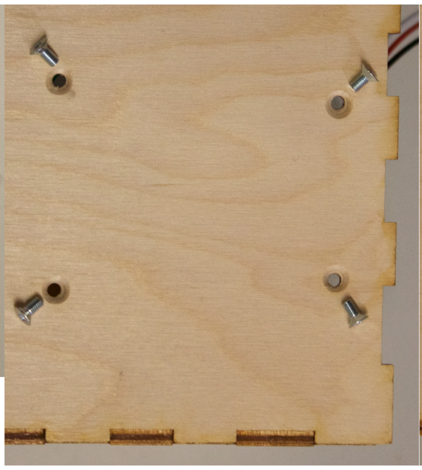
## Install LED

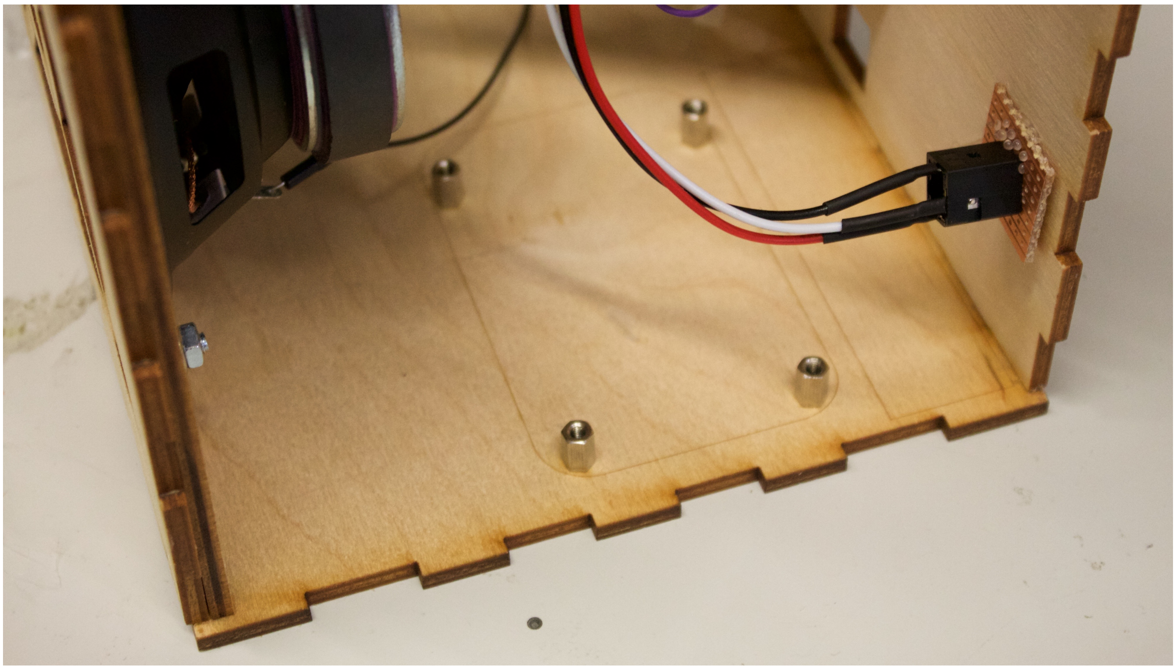




The **LED cable** should be attached to the **back plate** of the box from the *inside.* Put the LED into the hole, then secure it around the back using hot glue or superglue.

## Install the BeagleBone spacers

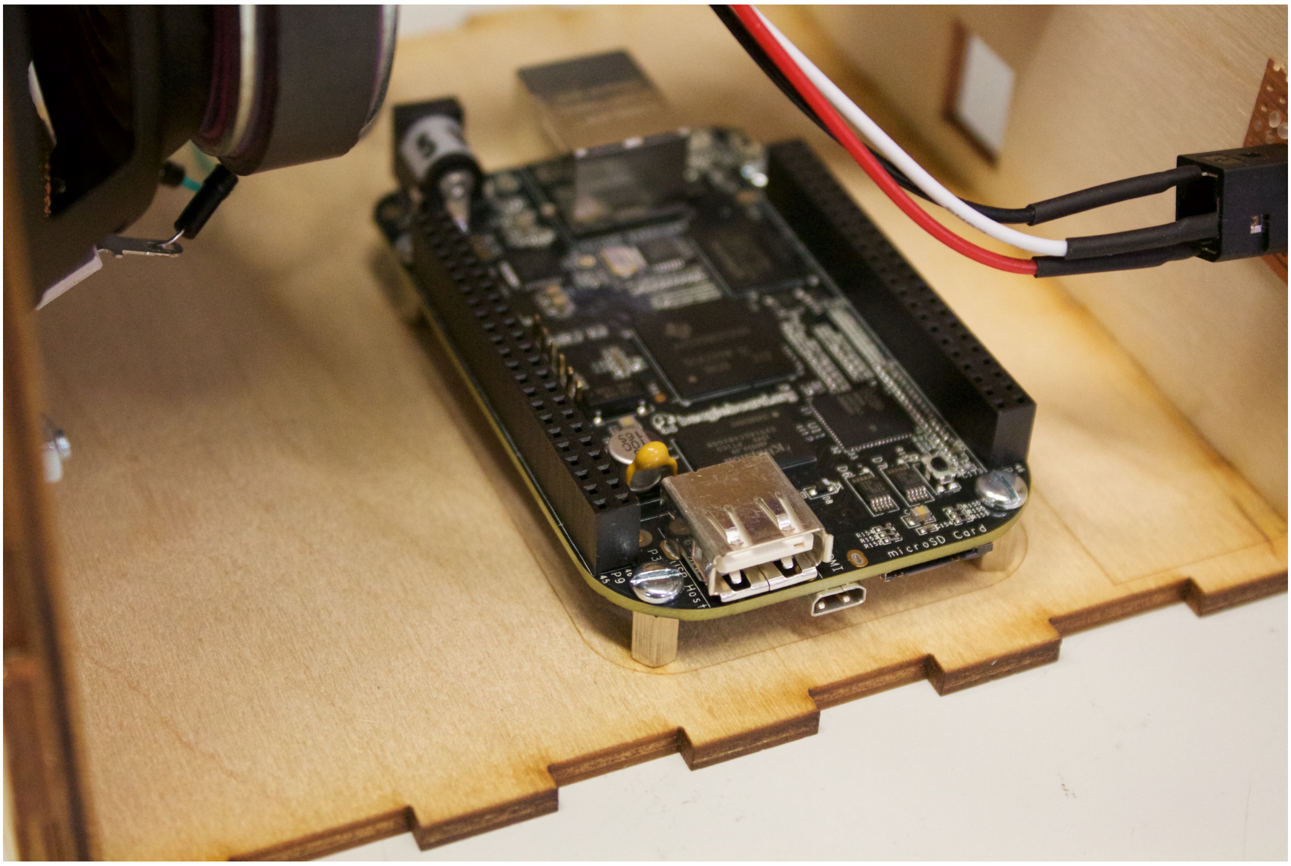



The BeagleBone Black will attach to the **bottom plate** of the box. Before installing it, we first need to install the **M3 hex spacers** which will secure it. Insert the four **M3 flat head screws** from the *outside* of the box and attach them to the **hex spacers** on the inside. The screws can be left finger-tight for now as this will make the next step easier.

The pan head screws will be used in the next step to secure the BeagleBone Black.

**Install the BeagleBone Black**

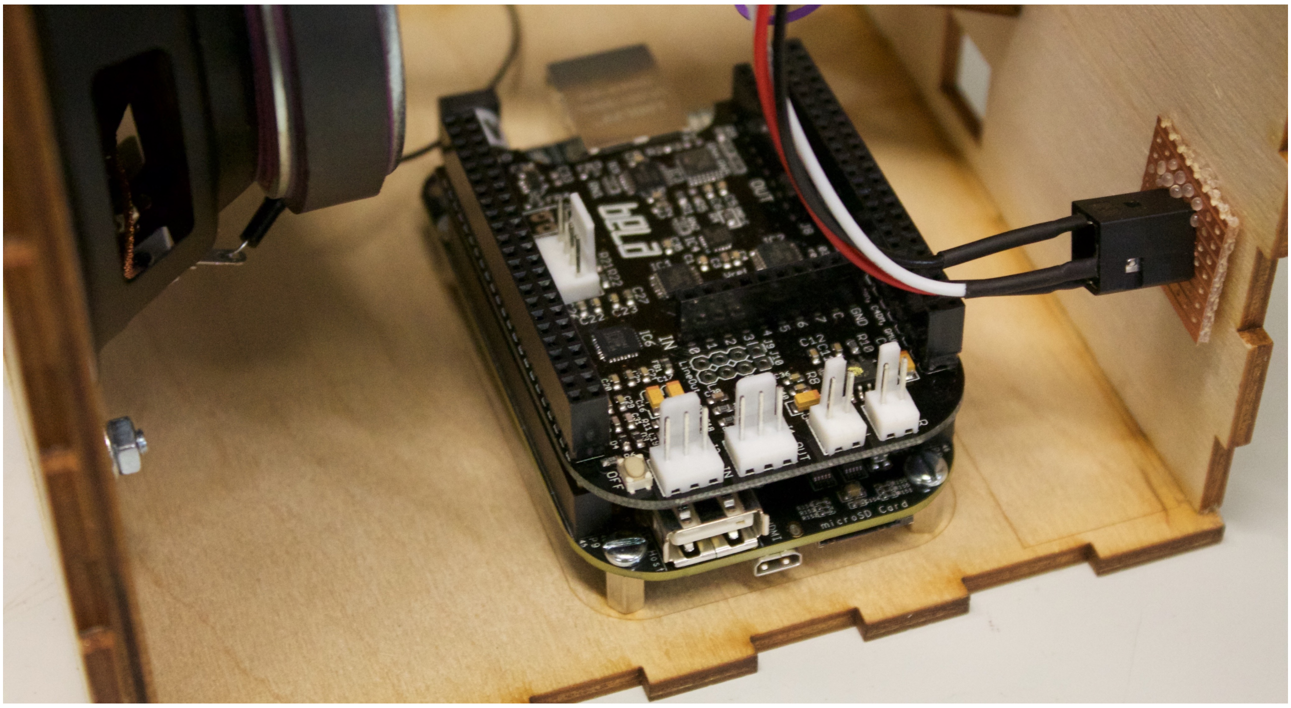


*(Note: screws in this image are slotted, but Phillips screws included in kit)*

Place the **BeagleBone Black** on top of the **spacers** such that the footprint aligns with the laser etching on the box. The SD card slot should face the *outside* of the box. Then secure the BeagleBone using the four **M3 pan head screws**. Tighten all the screws using a Phillips heads screwdriver.

**Tip:** the alignment of the holes is quite tight. If you have trouble getting a screw to go into one of the spacers, it may help to loosen the **flat head screw** on the outside of the box, so the spacer can move around a little bit. When both screws have threaded into the spacer, they can be tightened.

**Attach the Bela cape to the BeagleBone Black**

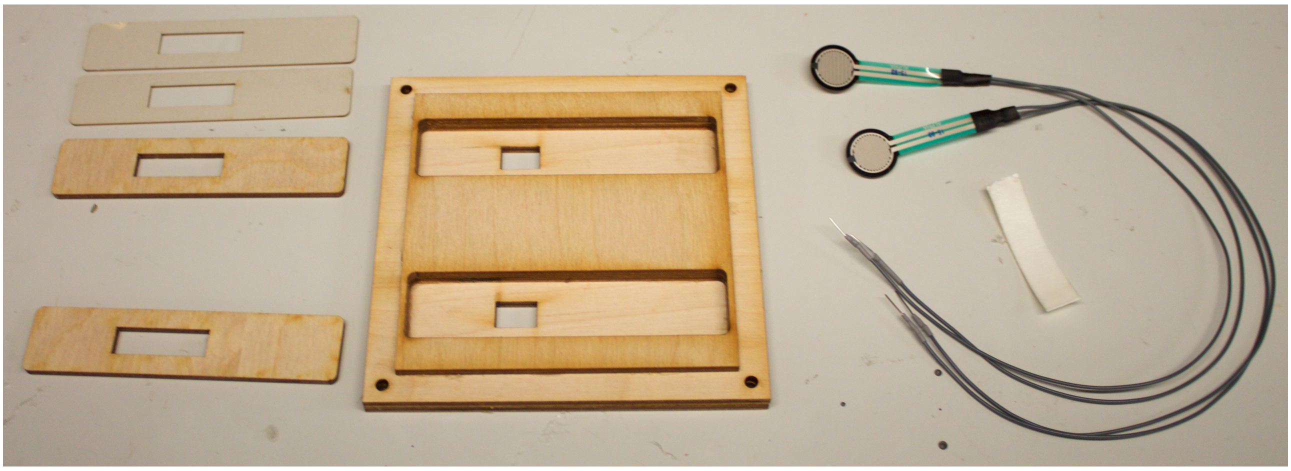


Once the **BeagleBone Black** is installed, the **Bela cape** should be placed on the top. Carefully line up the pins of the Bela cape to align with the sockets on the BeagleBone Black, making sure that the cape faces the correct direction. (The white connectors should face toward the outside of the box, above the SD card slot.)

Once the two boards are aligned, gently push down to attach the cape to the BeagleBone Black. The pins are slightly longer than the sockets, so it is normal for some of the pin to remain visible when the two are connected.

**Note:** this step is done after mounting the BeagleBone Black into the box because installing the cape makes it harder to reach some of the screw holes.

## Part 2: Build the Sensor Plate

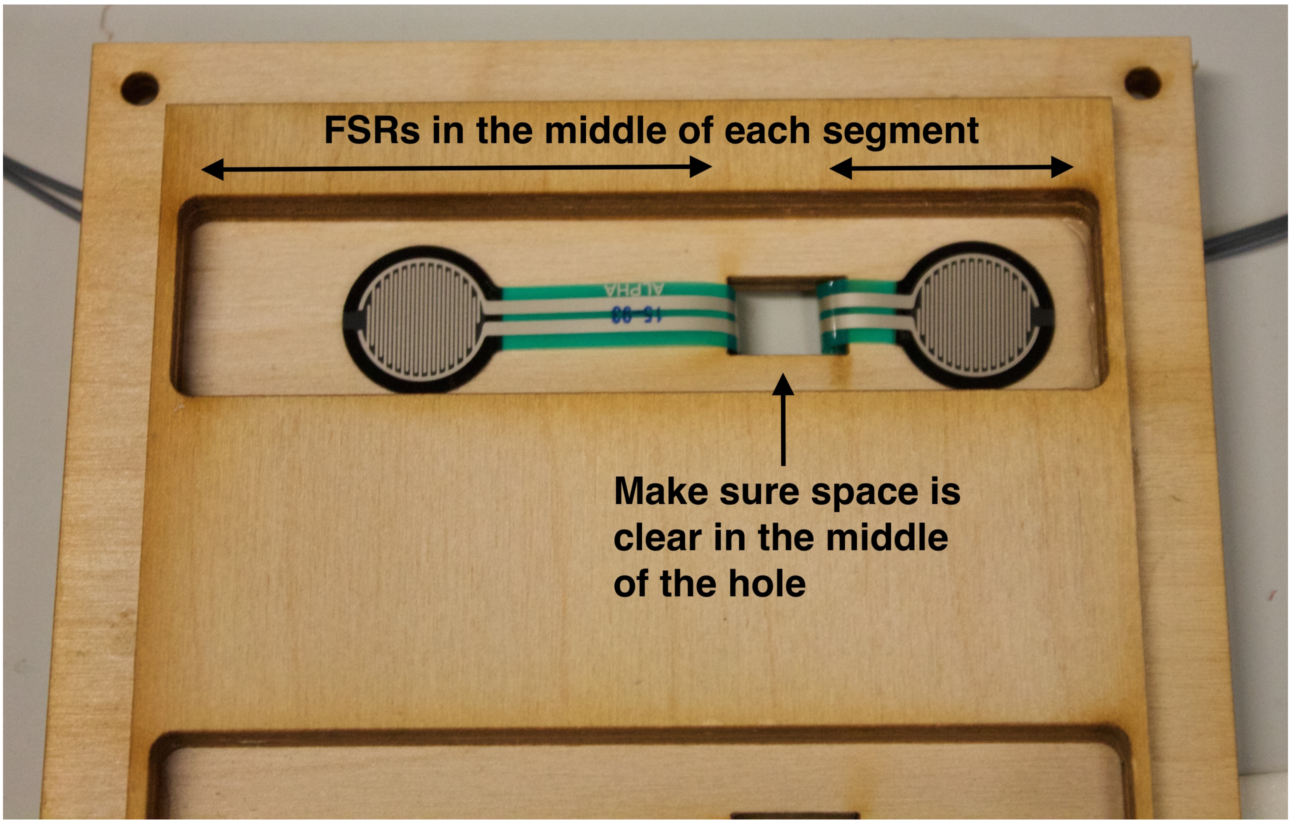


*(not shown in image: capacitive touch sensors and extra cardboard spacers -- 6 total in kit)*

The sensor plate contains the two capacitive touch sensors which measure the position of the fingers. Underneath one of them (the one that is further from the speaker when assembled), two force-sensing resistors provide a pressure-sensitive response.

The sensor plate consists of a stack of different materials whose assembly is explained in the following steps.

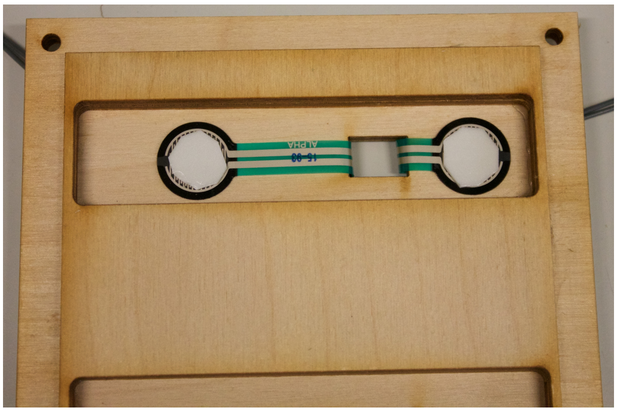
**Attach the force-sensing resistors to the plate**




The **force-sensing resistors** (FSRs) have adhesive backings. Peel off the back sheet to expose the adhesive, run the ends of the cables through the rectangular hole, then stick the FSRs into the sensor tray as shown. Notice that the rectangular hole is not centred in the top plate. Put each FSR at the midpoint between the edge of the hole and the side of the sensor tray. Make sure that the cable can bend cleanly around the edge of the square hole, and that there is still room to put a third cable through the middle.

**Note:** be sure the FSRs go into the correct tray. Orient the top plate so that the rectangular holes are on the right-hand side. Then the FSRs go into the tray that is *further* from you. (If you do this the other way around, it will still work, but the response of the instrument will go the opposite direction.)

## Attach the spacers above the FSR



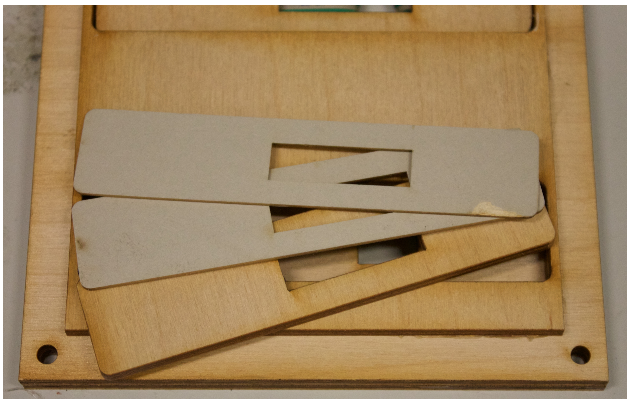
Using the provided **foam tape**, cut small circular sections that fit neatly into the middle of each **force-sensing resistor**. (Make sure the pieces are small enough that they fit in the middle and don't rest on the raised edges of the FSR.) Attach these to the top of the FSRs and peel off the other half of the adhesive backing.

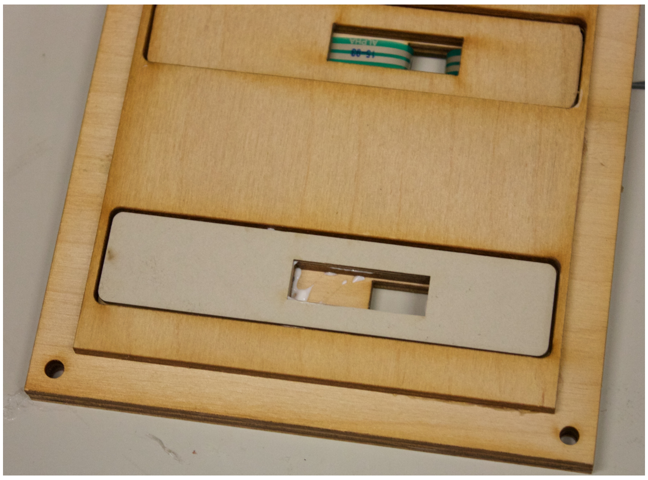
Next, place the **wooden spacer** into the tray on top of the tape. Make sure its hole lines up with the rectangular hole underneath, and that it fits cleanly into the tray and does not bind on the edges.

**Tip:** if you find it difficult to fit the spacer into the tray, you can use a utility knife to scrape around the edges of the tray to remove excess glue or bits of wood that may be sticking into the tray. If that is still not enough, heavy sandpaper can take the edges off the spacer so that it will fit in more easily.

Once this is done, add **two cardboard spacers** on top of the wooden spacer. *(Not shown in the images above.)* Spread a thin layer of superglue on each cardboard spacer, then stick it down onto the piece below it. Again, make sure the holes align with the holes in the pieces below.

## Attach the spacers in the other sensor tray



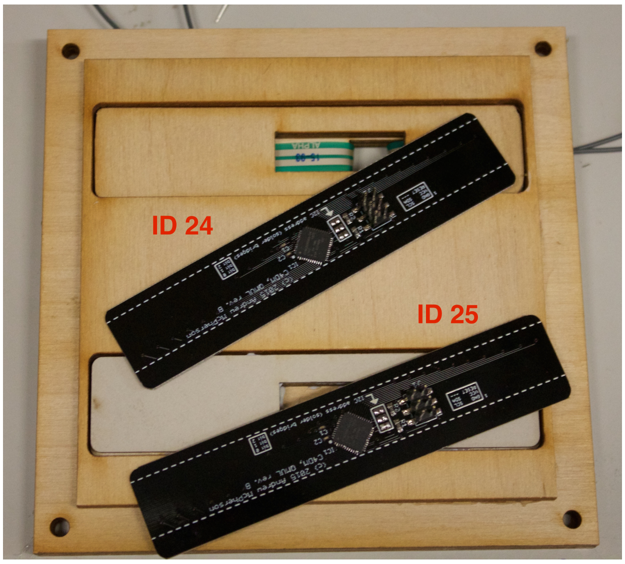


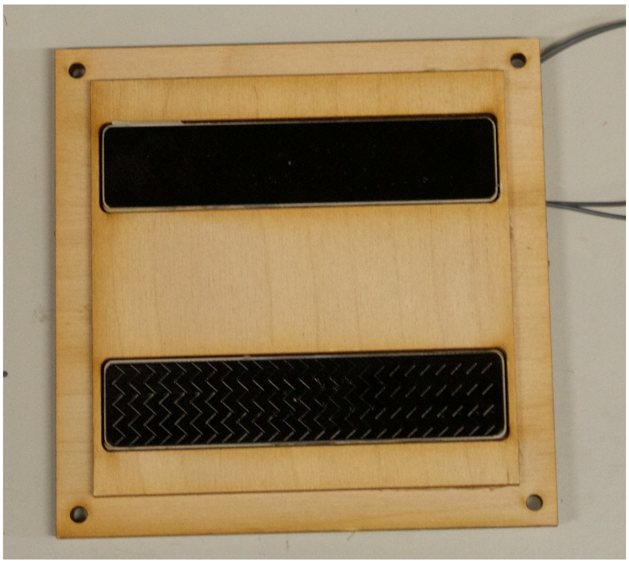
*(Note: above image shows two thicker cardboard spacers, where kit contains four thinner spacers)*

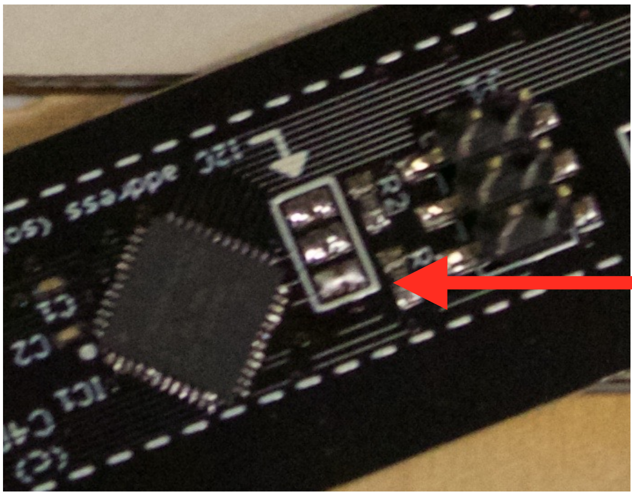
In the sensor tray that does *not* have the two FSRs, first add the **wooden spacer**, using wood glue (or optionally superglue) to secure it to the plate, making sure the holes line up. Then add **four cardboard spacers**, securing each to the one underneath it using superglue or wood glue. The height of the spacers should be such that the sensor is approximately level with the surface of the plate once it is installed.

**Tip:** wood glue takes longer to dry than superglue but will provide a more secure and more permanent long-term bond.

## Attach the touch sensors





This pad bridged on sensor ID 25

*(Note: in upper left image, cardboard spacers in top sensor tray not shown.)*

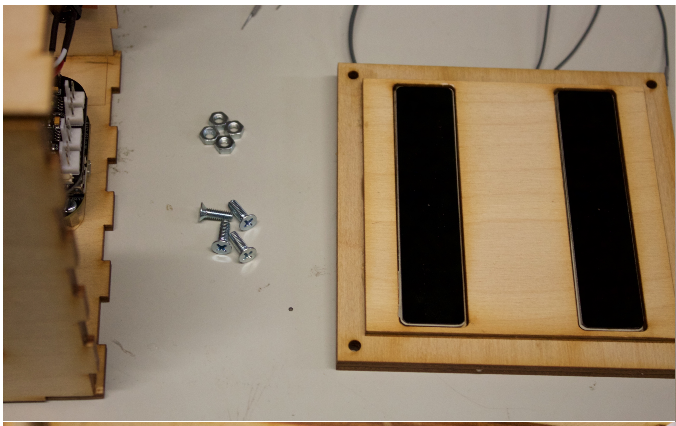
The **capacitive touch sensors** will be secured to the **spacers** beneath them using superglue.

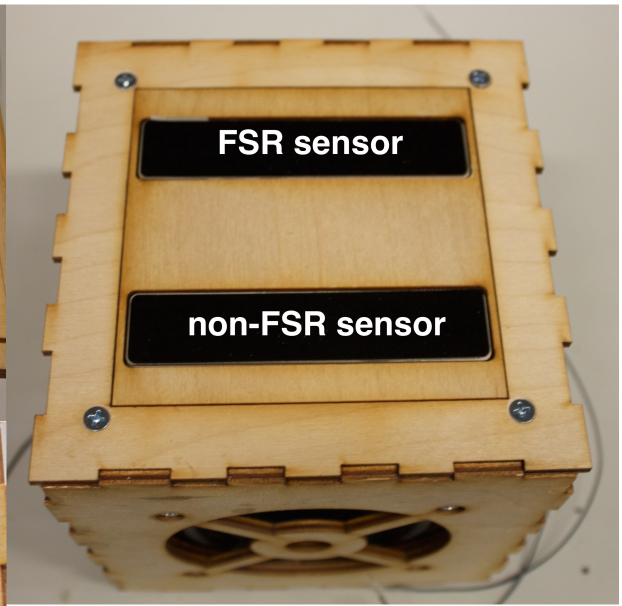
First (**important!**), make sure the right sensor goes in the right hole. One of the two sensors will have a sticker on the bottom saying *"24 - FSR"* and the other will be labelled *"25"*. If either sensor is missing the sticker, the sensors can be identified by looking at the pads in the box labelled *"I2C address"*. The sensor that goes in the tray with the FSRs will have *none* of the pads connected to one another, where the sensor that goes in the other tray will have a solder bridge across the two pads corresponding to *bit 0*.

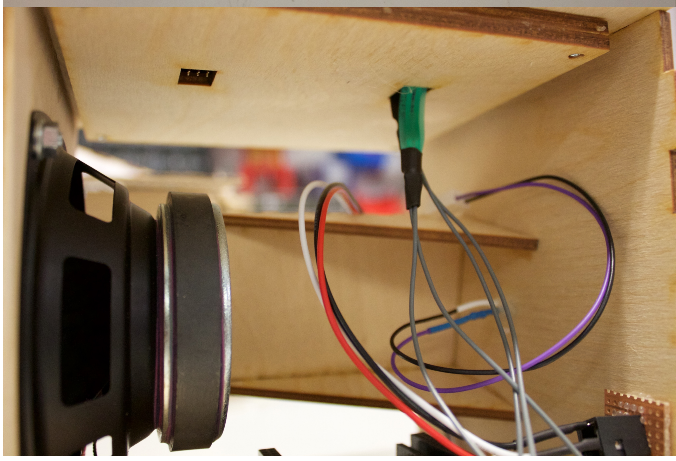
Once you have identified which sensor is which, attach them one at a time. Spread a thin layer of superglue around the top of the spacer, then press the sensor down and hold firmly across its entire area for 1 minute.

**Note:** put the glue onto the spacer, not onto the sensor itself, and keep the glue away from the very edges of the tray. This will reduce the likelihood of glue spilling up onto the top surface of the sensor. If glue does get onto the top surface, it can be rather difficult to remove. It does not impeded the operation of the sensor but it can be unsightly.

## Attach the sensor plate to the box



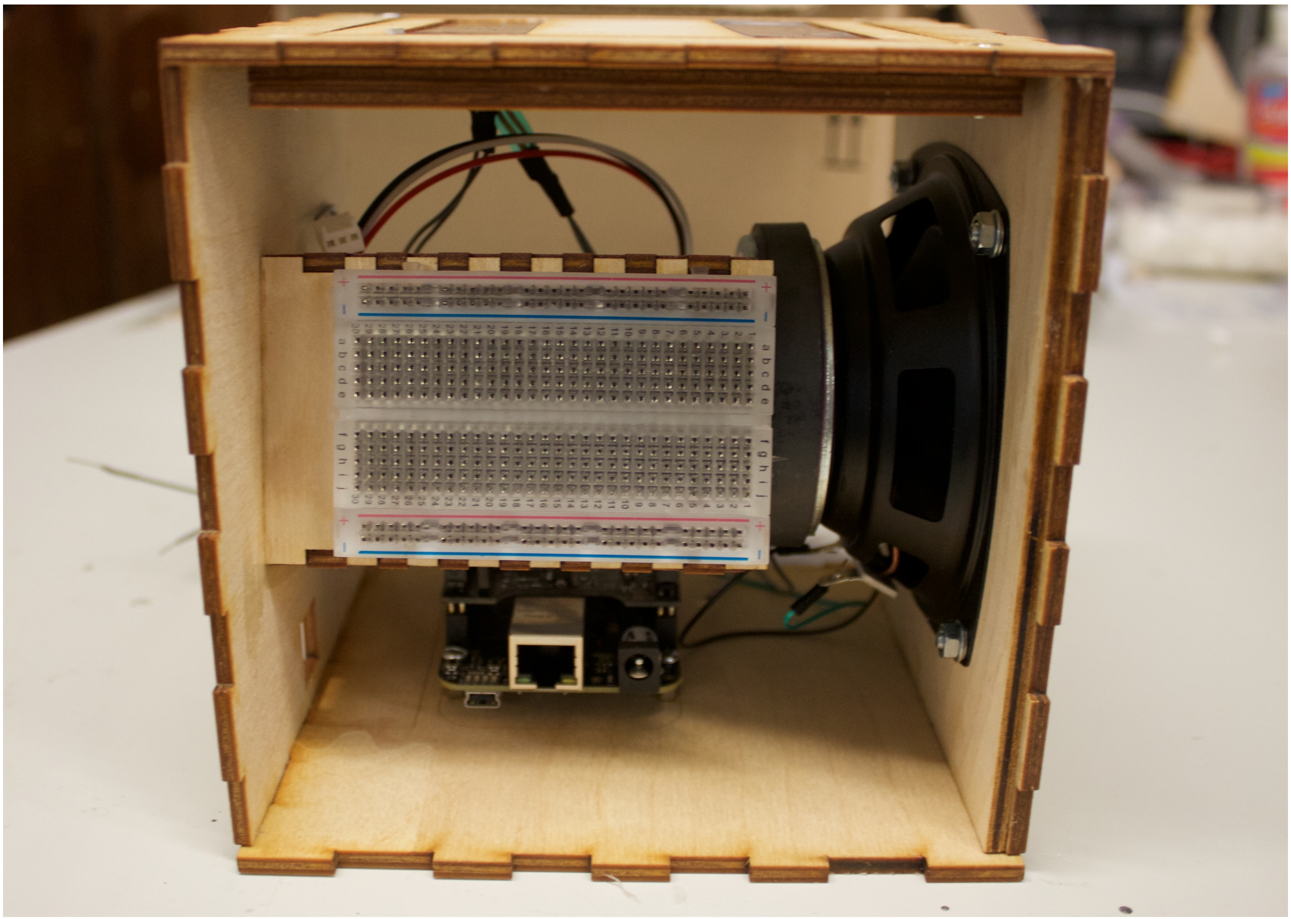


The assembled sensor plate fits inside the top piece of the box. Slide it inside the box so that the sensors are parallel with the speaker and the force-sensing resistors are under the sensor which is *further* from the speaker.

Secure the sensor plate to the top of the box using the four **M4 flat-head screws** and the remaining four **M4 nuts**. (The other four nuts will have been used to attach the speaker.) Tighten the connections using a Phillips screwdriver.

**Attach the breadboard**



The **breadboard** attaches to the **breadboard wing** wooden piece inside the box. Peel off the adhesive backing on the breadboard, and the adhere it to the breadboard wing, near the middle of the box. (If you put the breadboard right up against the edge of the box it will be harder to manipulate wires near the side.)

## Part 3: Internal Components

The following steps will install the rest of the internal components inside the D-Box case.

**Install the battery**

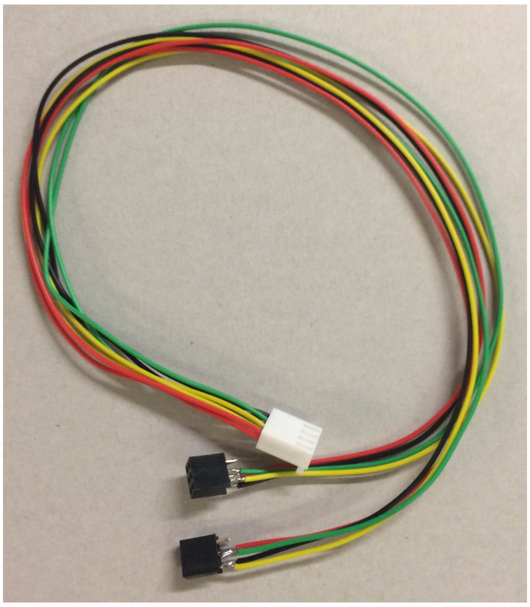
Take the two **velcro strips.** Attach the soft (loop) side of each piece to the **battery**: the shorter piece should be on the same side of the battery as the power button. The longer piece should be on the adjacent side: if you place the battery with the button facing upwards and to the right, the other piece of velcro will go on the side which faces you.

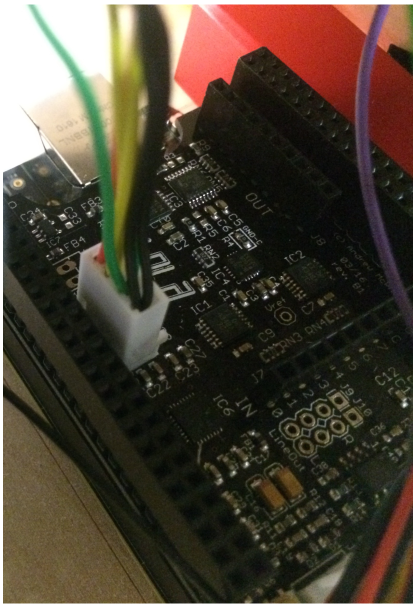
Next, take the rough (hook) side of the velcro and place it inside the box in the corner between the **back** and **bottom plates**. One piece should go on the bottom plate, within the etched outline for the battery; the other piece should go on the back plate, next to the window and towards the audio jack.

**Tip:** if you have problems getting the velcro to stay adhered to the wooden case, you can affix it using superglue. It is also possible to mount the battery directly into the case with hot glue, but this makes it harder to swap later.

Once the velcro is installed, the battery can be placed inside the case such that the power button and indicator light show through the window in the back of the case.

## Connect the I2C touch sensor cable

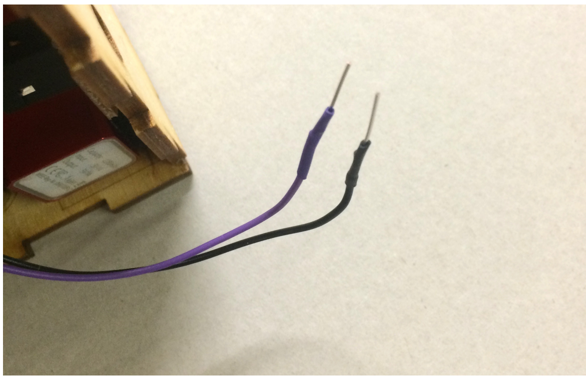


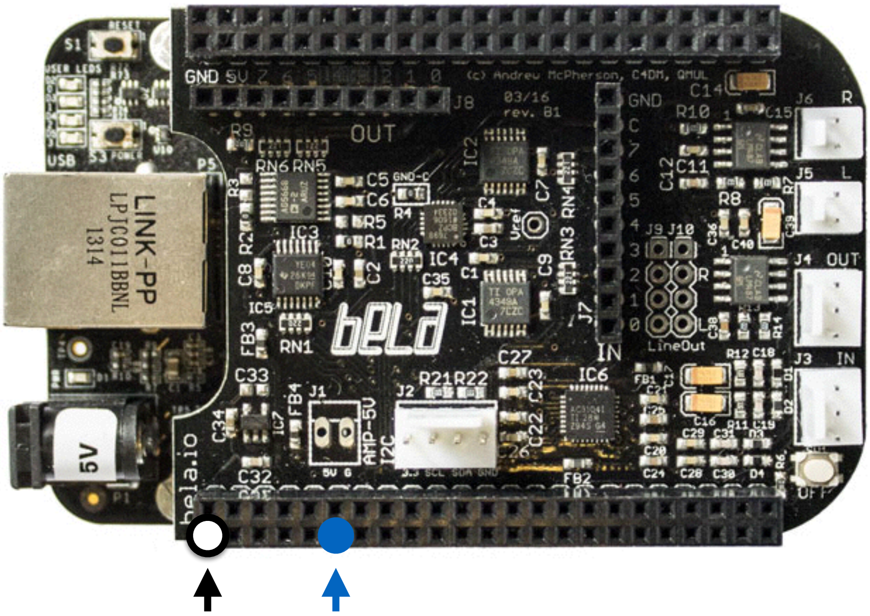


The **I2C touch sensor cable** has two black 6-pin sockets on one side and a white 4-pin socket on the other. The black 6-pin sockets connect to the **touch sensors** in the top plate. For the touch sensor with the **force sensing resistors** beneath it, make sure the I2C cable fits in the middle between the two FSR cables.

**Important:** the 6-pin sockets can connect in either orientation, but only one of them will work properly. Notice that the 6-pin sockets have only 4 wires attached. Looking at the top plate with the rectangular holes toward the side facing you, the 4 wires should face to the *right*. If your D-Box follows the layout in the photo, that means the 4 wires will face *away* from the speaker.

On the other side, the 4-pin Molex connector goes into the matching header on the Bela cape. There is only one way this connector will fit.





Black (negative)
to P9, pin 2

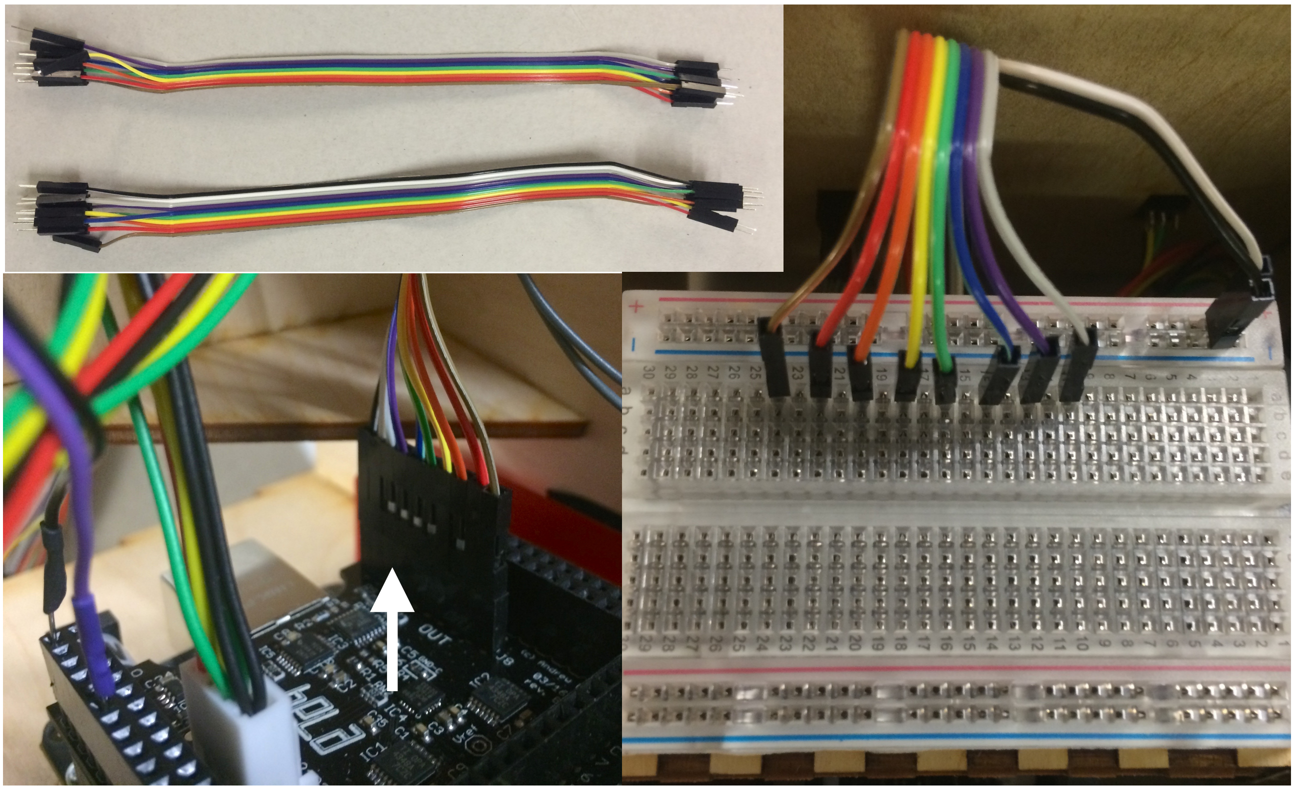
Blue (positive)
to P9, pin 12

The **LED**, which was previously glued into the box, has two wires coming out of it. One is black, the other will typically be blue or purple. The blue/purple wire is *positive*, the black is *negative* or *ground*.

Insert the black wire into pin **P9_01** or **P9_02** on the Bela cape. Looking at the cape from the side with the SD card and white connectors, these are on the left connector, the furthest into the box. Then, connect the blue/purple wire to pin **P9_12**. This is on the left connector, left-hand column, 6 rows down from the end. (See diagram.)

**Important:** the location of the blue/purple wire is particularly sensitive as the adjacent pins serve important internal functions for Bela. If the wire is connected to the wrong pin, the Bela environment may not run properly.

**Connect the jumper wire ribbon to the analog output**



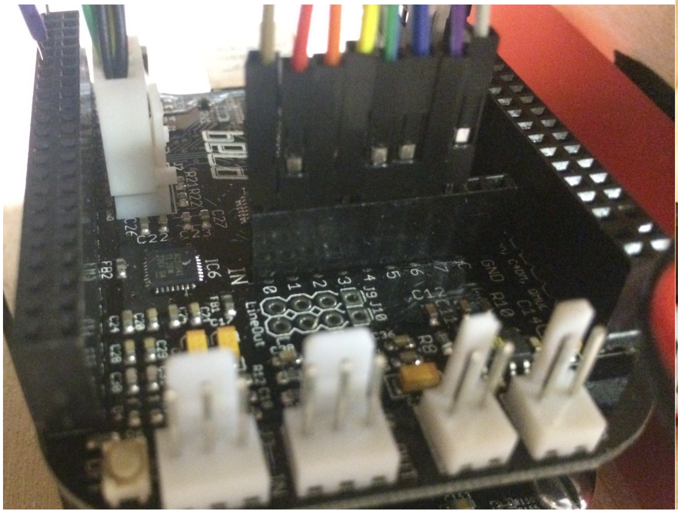
A 20-pin multicoloured **jumper wire ribbon** is included in the kit. This should be split into two smaller ribbons of 10 and 8 wires, respectively. The 10-wire ribbon should begin with a *brown* wire and end with a *black* wire. The 8-wire ribbon should begin with a *brown* wire and end with a *grey* wire. (There will be two extra wires, white and black, which are not needed.)

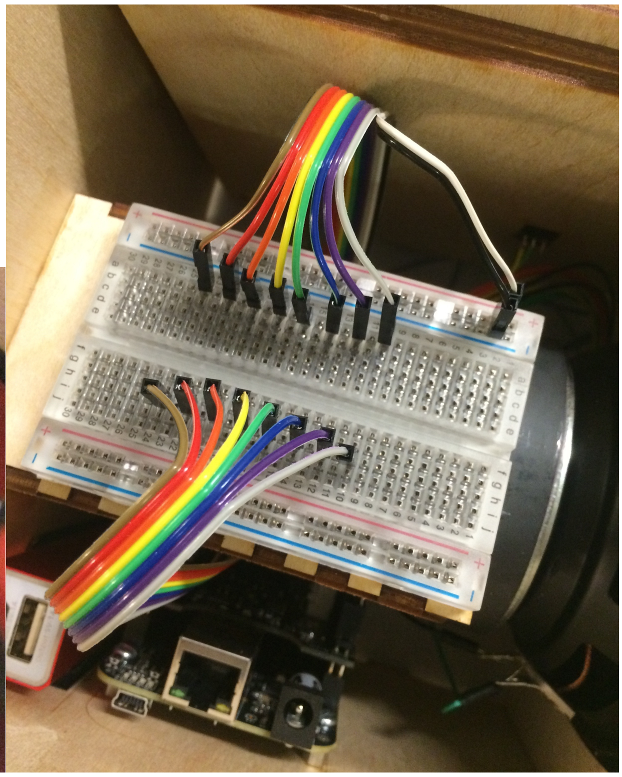
After splitting the ribbon, take the *10-pin* section and connect it to the **analog output** connector on the Bela cape. This is the connector furthest into to the box when viewed from the SD card side. Pay close attention to the order of the wires, which should begin with brown closest to you (*analog output 0*) and end with black furthest away from you (*ground*). **See diagram on next page.**

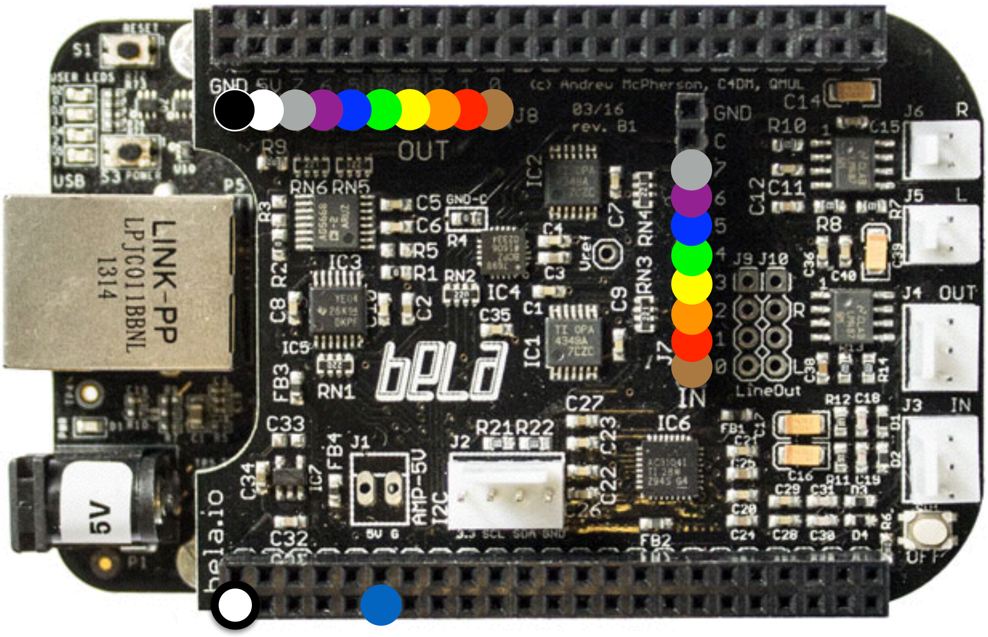
When you have connected the ribbon to the Bela cape, run it up and over the breadboard wing. Connect the wires into the **breadboard** as shown, with the *brown* through *grey* wires spaced 2 columns apart approximately in the middle of the breadboard. The *black* wire should go into the *blue* (negative) horizontal rail at the top of the breadboard; the *white* wire should go into the *red* (positive) horizontal rail.

**Tip:** you may find it helpful to split the white and black wires apart from the brown through grey wires a couple inches before the end, to make it easier to stretch them to the edge of the breadboard.

## Connect the jumper wire ribbon to the analog input



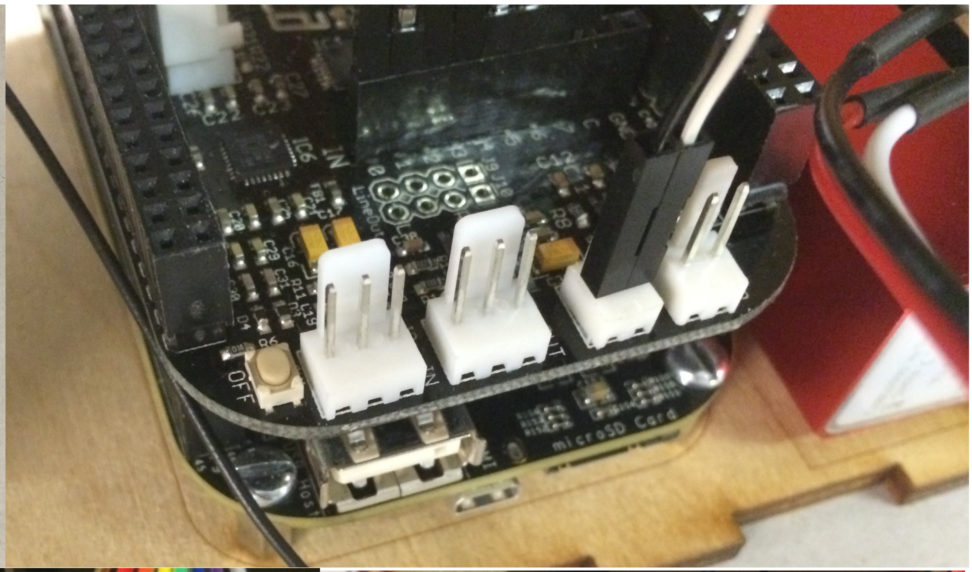
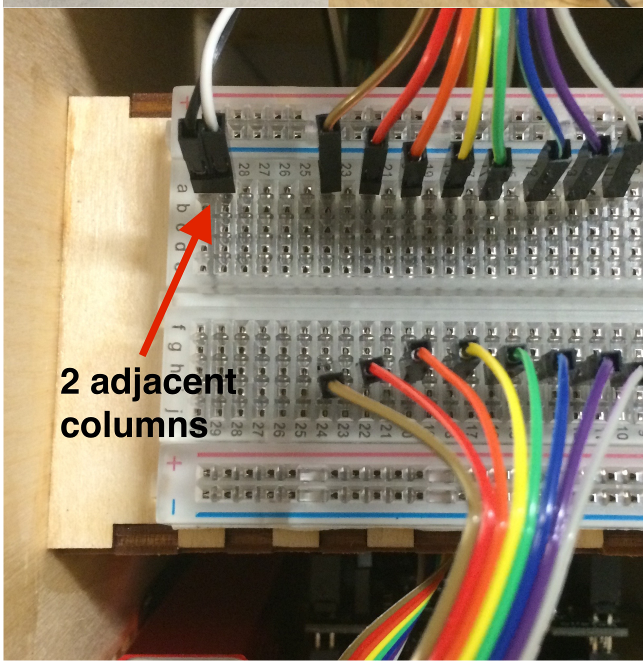


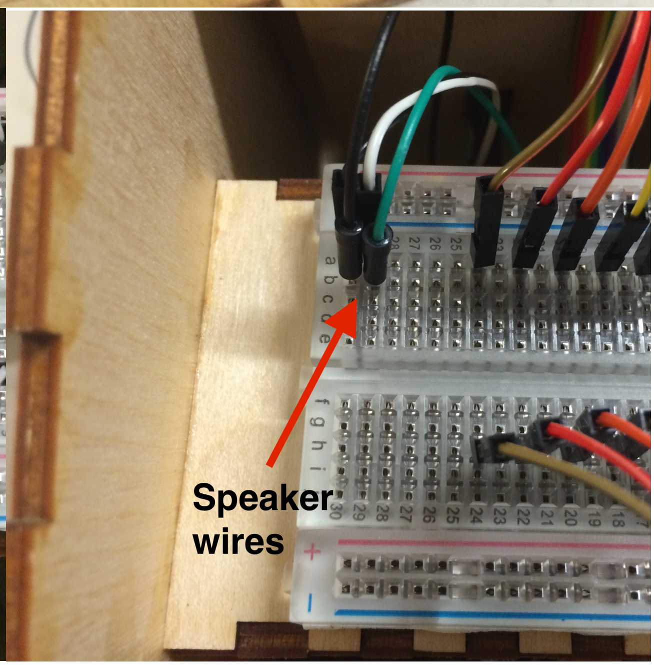



Connect the 8-position **jumper wire ribbon** to the **analog input** connector of the Bela cape. The connector is 10 pins, and the cable should be connected to the *leftmost* set of pins when viewed from the SD card side (the pins corresponding to analog inputs 0 through 7).

Run the ribbon out beneath the breadboard wing and connect it into the bottom half of the **breadboard** as shown. The colours should go in the same order and the same columns as the ribbon at the top of the board, which means that they should be spaced 2 columns apart, roughly in the middle of the breadboard.

**Connect the speaker**



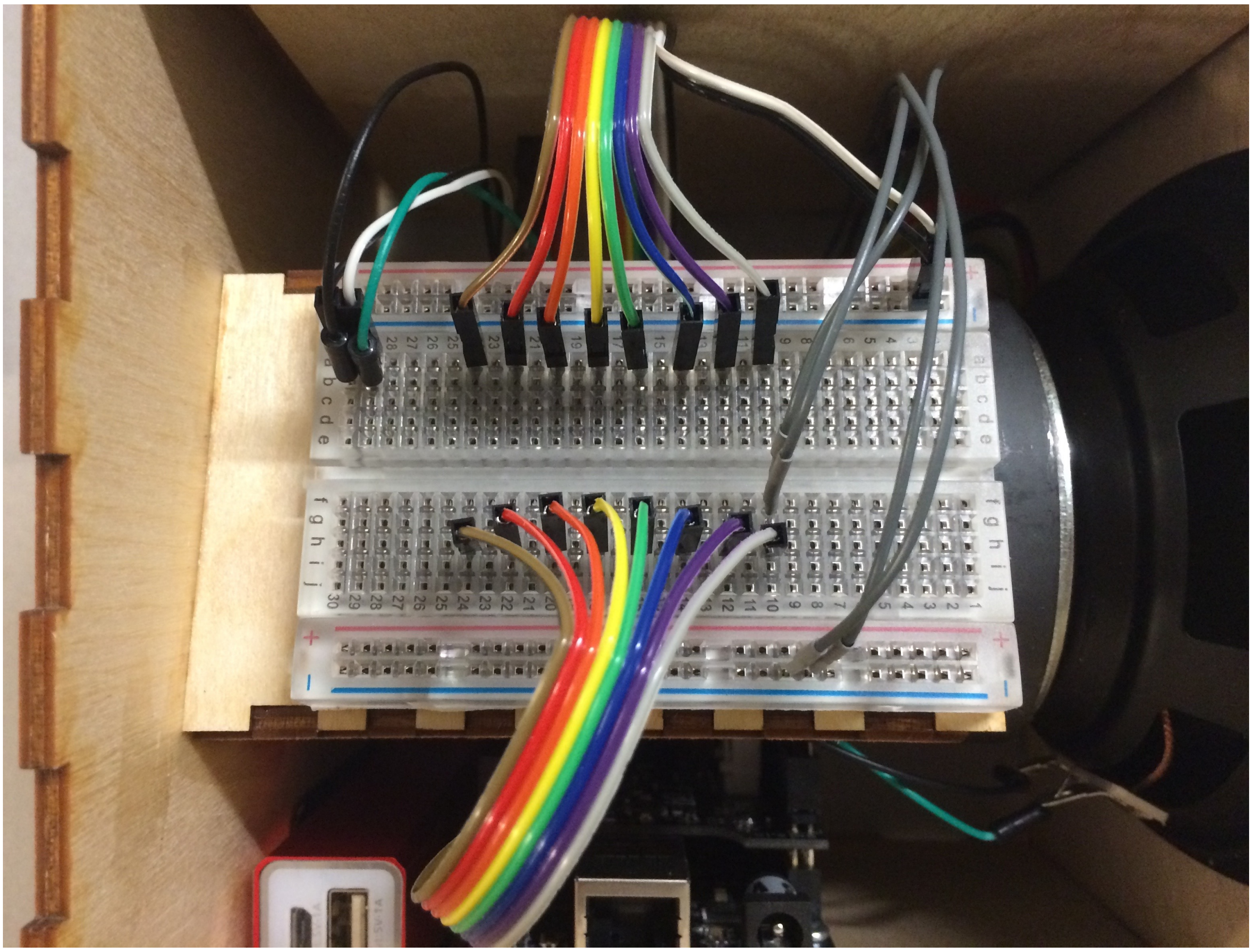

The speaker does not connect directly to the Bela cape. Rather, a cable runs from the cape to the breadboard, and the speaker connects there, so it can be rewired by the performer at a later point.

Locate the **2-wire pin-to-socket ribbon** (note: *not* the leftover 2-wire pin-to-pin ribbon from the previous step). Connect the socket end to the left of the two **speaker connectors** on the Bela cape. (It should work equivalently on either connector, with either wiring direction.)

Run the wire up and above the breadboard wing and connect it to two adjacent columns in the upper left of the **breadboard**. **Important:** do not connect the two wires to the *same* column or the board will not power on!

Next, run the two wires from the **speaker** up above the breadboard wing and attach them to the breadboard in the columns matching the wire ribbon.

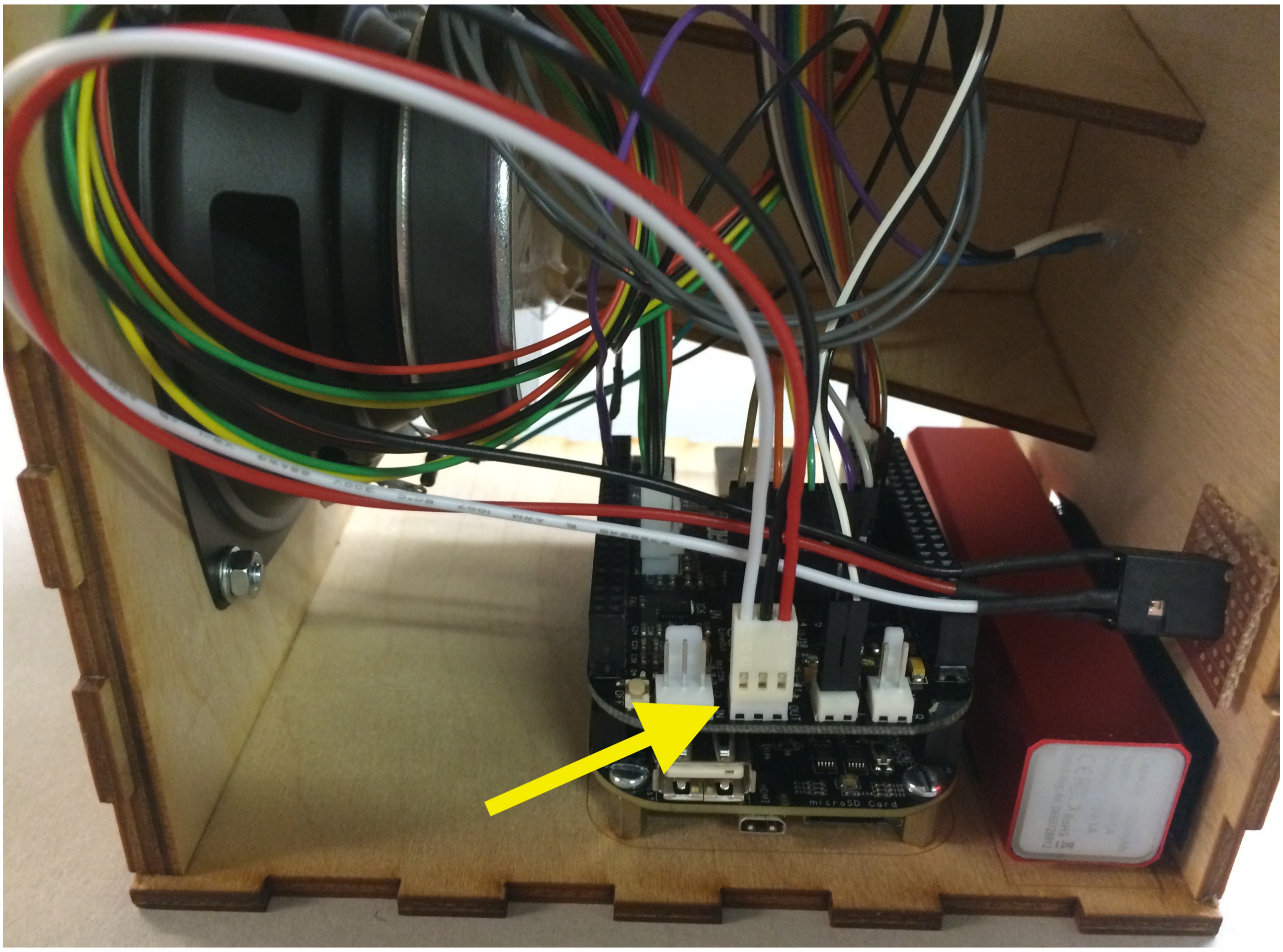
## Connect the force-sensing resistors



The **force sensing resistors** (FSRs) each have a 2-pin cable coming from them. The two FSRs should be electrically wired in parallel.

Take one wire of each FSR and put it in the same column as the *grey* analog input wire at the *bottom* half of the breadboard. The other wire from each FSR should go to the *blue* (negative) horizontal strip at the bottom of the breadboard.

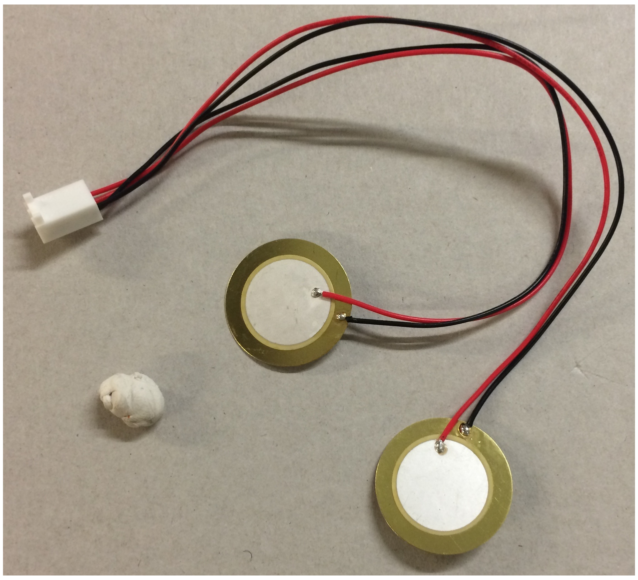
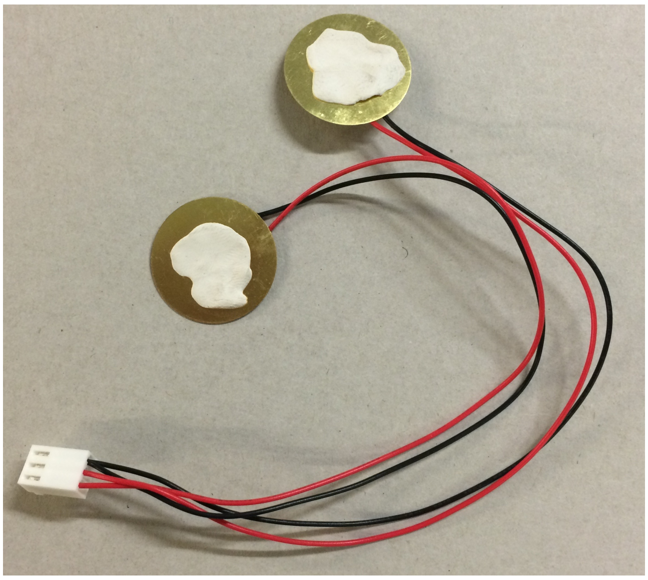
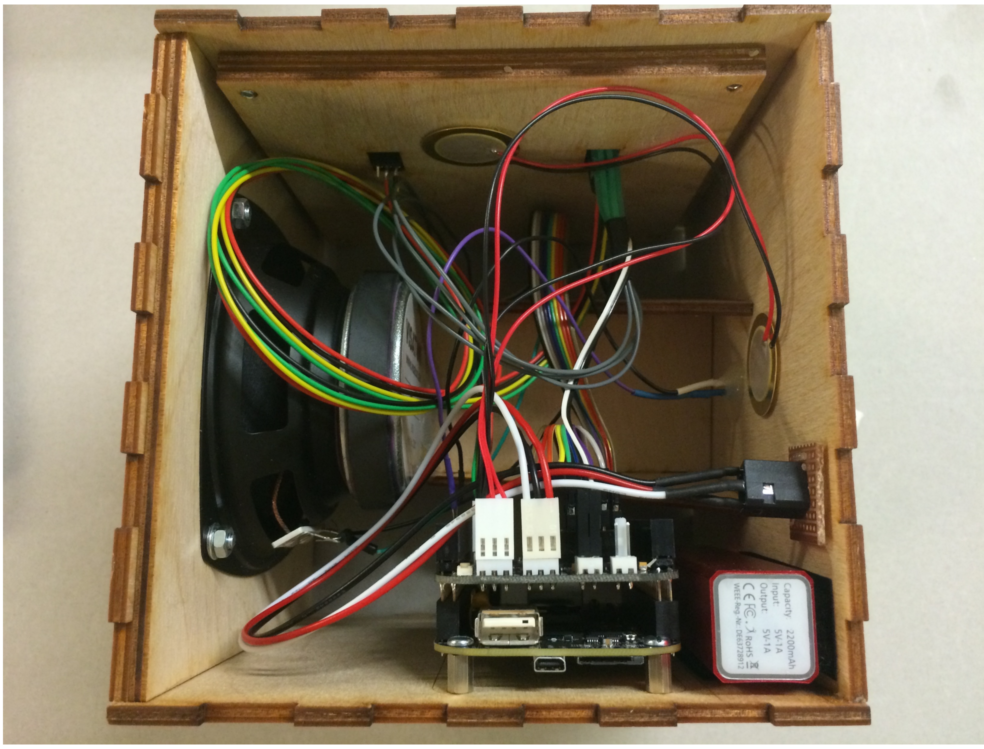
**Connect the headphone jack**



*(note: colour order of wires on the shipping cables are black-white-red, not white-black-red, though wiring is the same)*

Connect the 3-pin Molex connector on the **headphone cable** into the **audio out** connector of the Bela cape. This is the 3-pin connector toward the middle of the board (the leftmost connector being audio in).

## Connect the piezo pickups

The **piezo pickups** are attached to a cable with a single 3-pin Molex connector on the end. First, place a bit of **putty** on the back of each piezo disc to prepare it to attach to the box. It helps to work the putty in the hands for a minute and stretch it into thin circles before attaching it to the piezos.

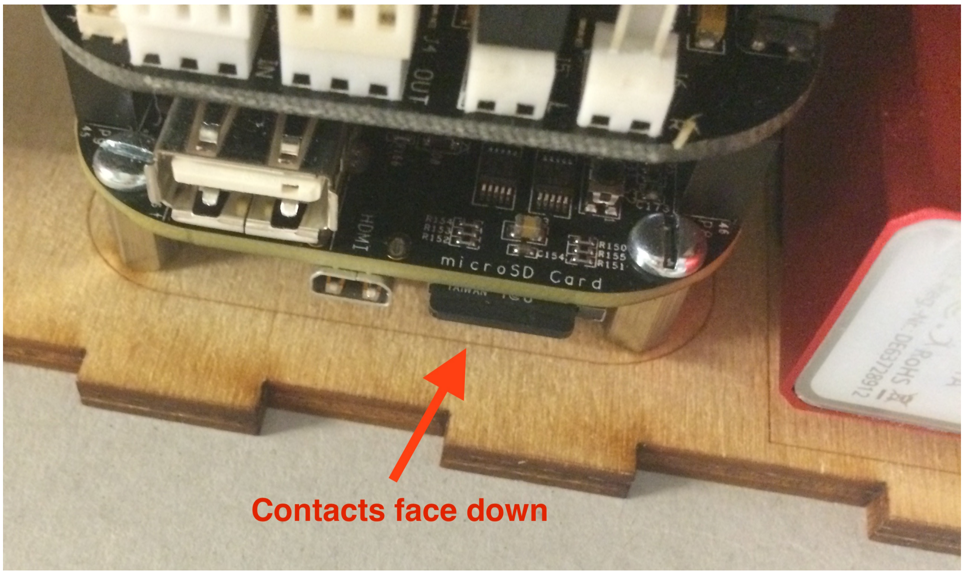
Next, connect the 3-pin connector to the **audio input** connector on the Bela cape (the leftmost connector when looking at the connector / SD card side). Attach one piezo to the *top* surface of the box, the other to the *back* surface.

## Connect the USB barrel cable

The **USB barrel cable** runs from the **battery** to the **BeagleBone Black** to power the system. (There is a second connector on the battery, a micro-USB port, which is used to charge it.)

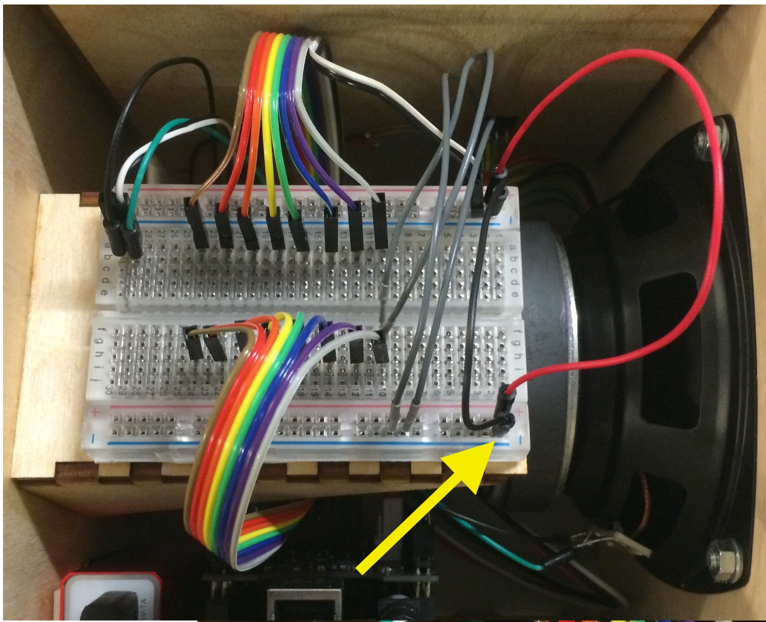
Once the cable is connected, tuck the excess length inside the box so it won't interfere with closing the side panel.

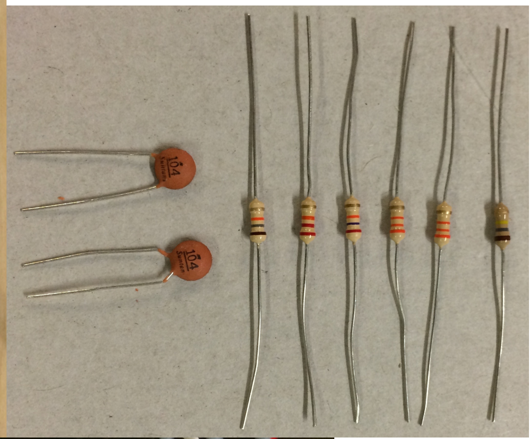
**Insert the microSD card**

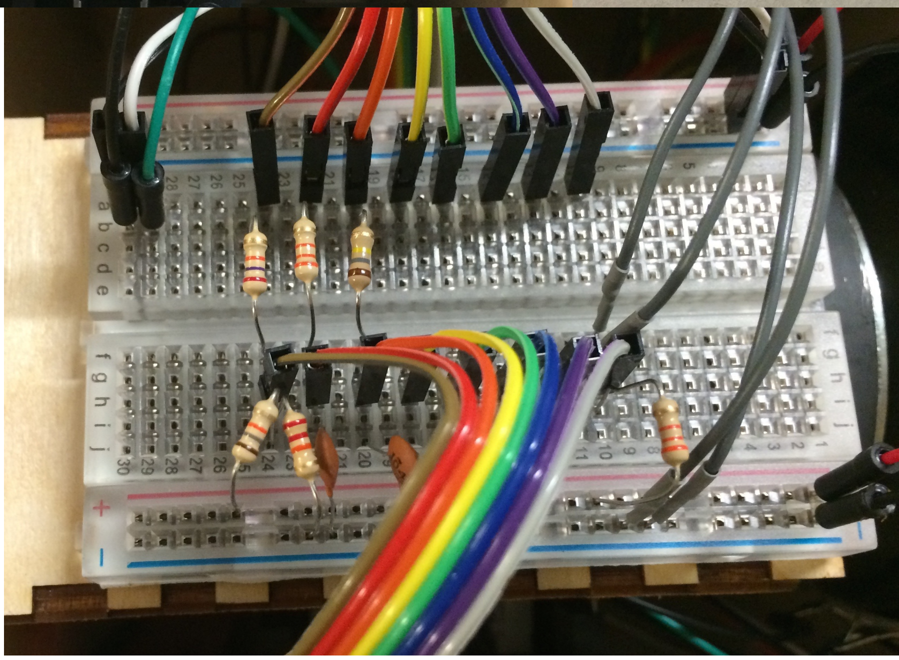



Remove the **microSD card** from its envelope and adapter (which is needed only for flashing it from a computer). Insert the SD card into the **BeagleBone Black** with the metal contacts facing *down*. Push it gently until it clicks into place.

## Populate the breadboard components





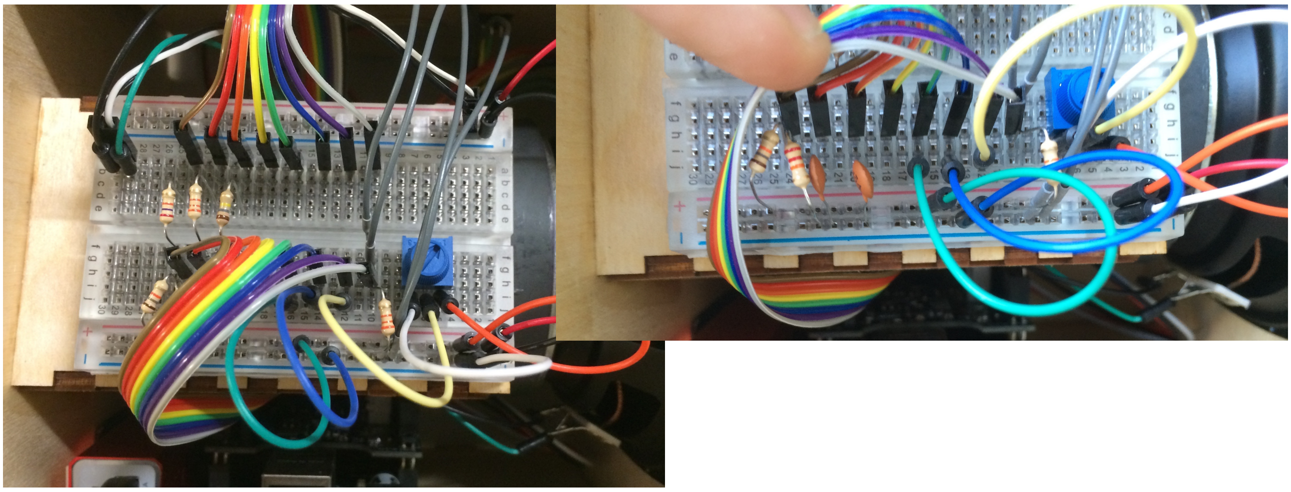


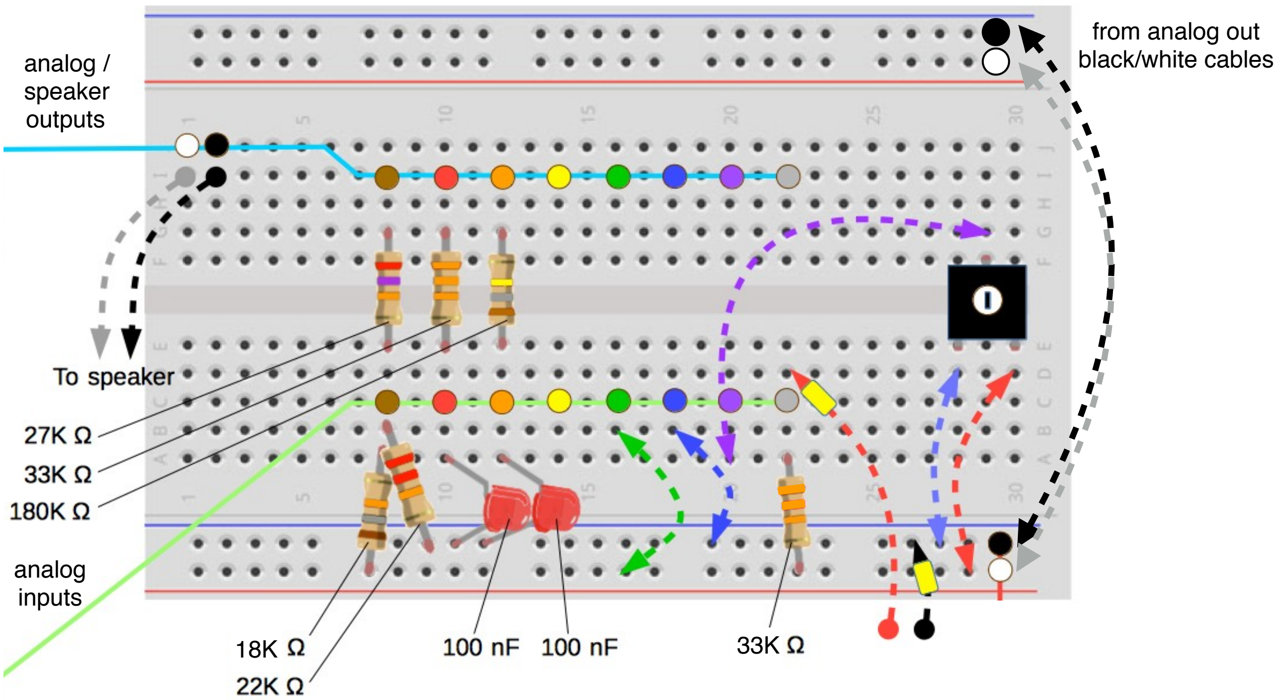
First, take two wires from the **bundle of jumper wires** and use them to connect the *blue* and *red* horizontal strips at the top and bottom of the breadboard. In other words, one wire should run from the blue strip at the top to the blue strip at the bottom; the other wire should run from the red strip at the top to the red strip at the bottom.

Next, locate the 6 resistors and 2 capacitors needed to populate the breadboard. Both capacitors are the same, but the resistors are of different values. Refer to the colour codes on the resistors and the diagram to see where each part should be connected. **See diagram on the next page for circuit layout.**

**Tip:** you can clip the leads of the resistors and capacitors if you want so that the components sit flush with the breadboard. However, the D-Box is designed for circuit-bending and it is easier to change wiring later if you leave the long leads on the components. Just be careful that the exposed legs do not touch each other and create inadvertent short circuits (at least, not until you start circuit bending it!).

## Add the potentiometer and the breadboard jumper wires



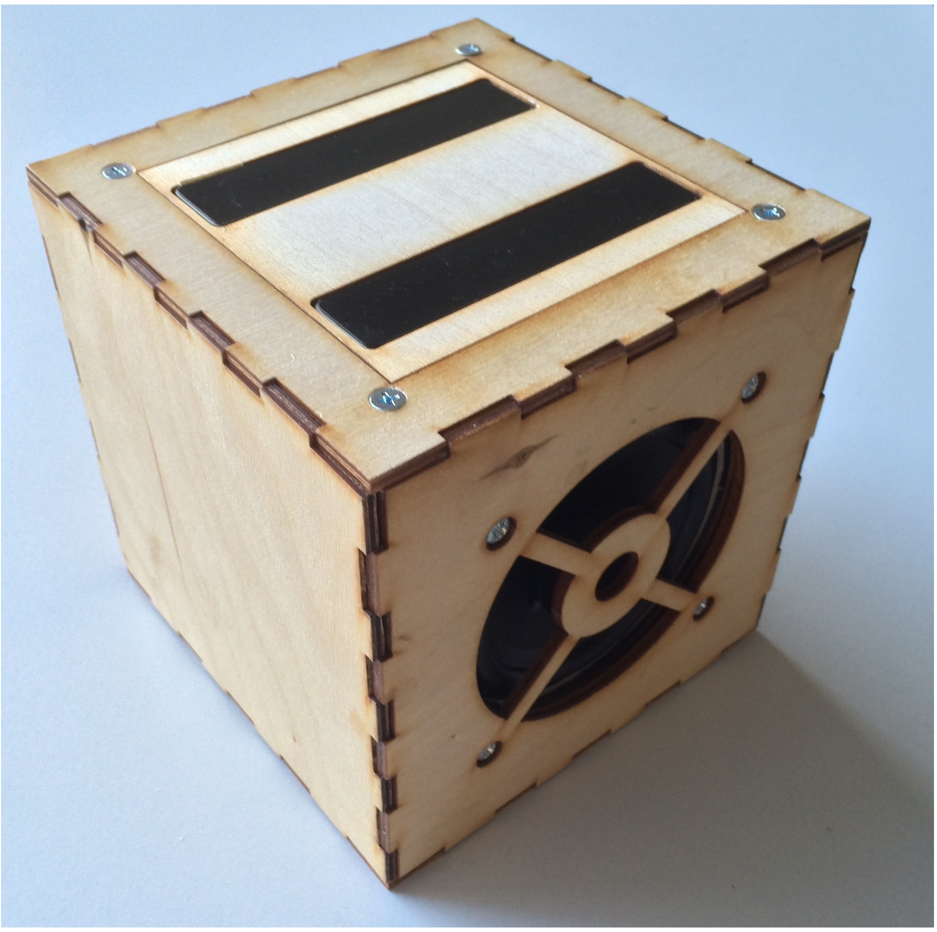



The blue **potentiometer** should be inserted in an unoccupied space toward the *bottom left* of the breadboard. It requires three jumper wires to attach to three adjacent columns. The wires on the outside columns go to the red and blue horizontal rails (positive and negative, respectively). The *middle* jumper wire should attach to the same column as the *purple analog input*.

The other jumper wires to install are:
* *green analog input* to *positive rail* (red horizontal strip)
* *blue analog input* to *negative rail* (blue horizontal strip)

**Note:** the kit contains a second potentiometer which is not needed in the default wiring of the D-Box, but you can use it for rewiring experiments later.

**Close the box**



**Assembly is now complete!** You can now close the side panels on the box to see the finished product. Generally speaking, the side panel facing the breadboard side is often removed for hacking on the breadboard, where the side panel on the other side can be kept shut most of the time. In fact, you will need this side panel open to do the next step involving the software.

You may need to charge the battery before the D-Box is ready to power up. While you do that, you can still move ahead to the next step preparing the D-Box software.

## Part 4: Prepare the D-Box software

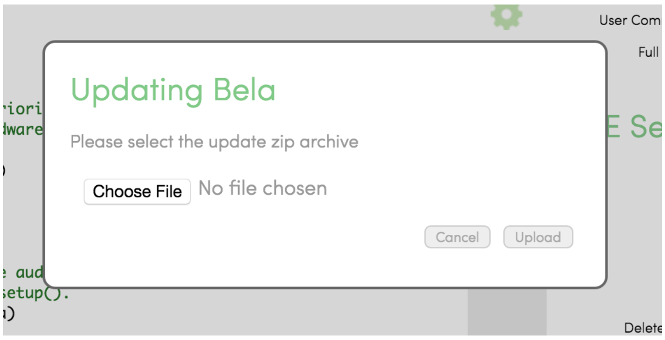
### Update Bela software

Connect the BeagleBone Black to your computer using the **mini-USB cable**. After it has booted (ca. 20 seconds), bring up the **Bela IDE** by pointing your browser to the address :

*http://192.168.7.2*

Once the IDE loads, the first step is to update the Bela software to the latest version, which will have improvements and bug fixes in the D-Box code (amongst other features). Go to *https://github.com/BelaPlatform/Bela* to access the repository and download a .zip archive of the repository (you do not need to uncompress it).

Next, go to back to the Bela IDE and click on the *Settings* tab (looks like a gear). Click the button labelled "Update Bela" which will pop up a dialog box asking for a file containing the Bela code. Select the .zip archive and confirm that you want to upload this to the board. It may take 15-20 seconds to update the board, after which you will need to refresh the browser page for your changes to take effect.

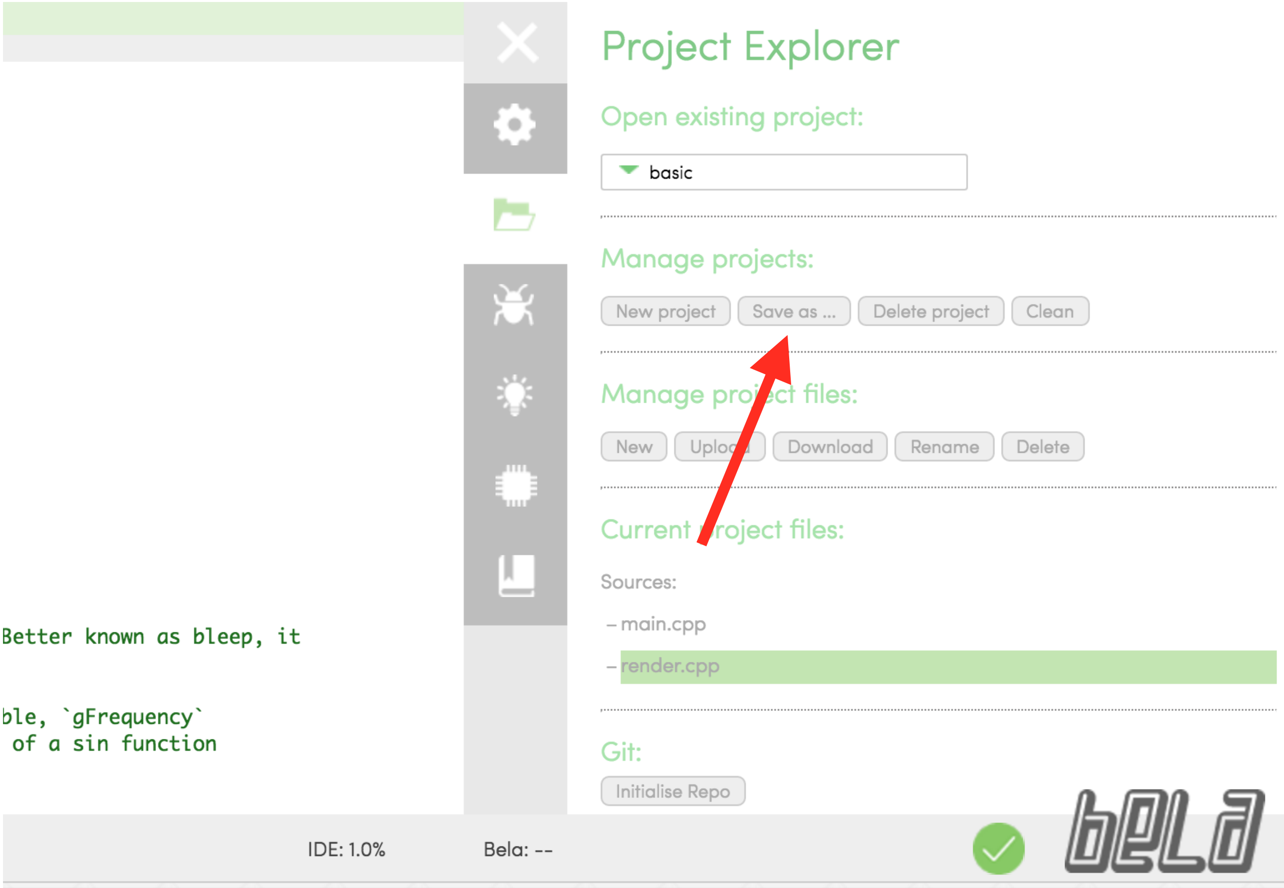



Further information on updating Bela can be found at:
*https://github.com/BelaPlatform/Bela/wiki/Updating-Bela*

**Load D-Box example and save a new project**

In the Bela IDE (*http://192.168.7.2*), go to the *Examples* tab (which looks like a light bulb) at the right-hand side of the browser and load the example named **10-Instruments/d-box**.

When the code comes up, the first thing to do is to save the example as your own new sketch, which will let you modify the code and add sound files for the D-Box. In the *Files* tab (looks like a folder), click *Save As...* and give your project a name.



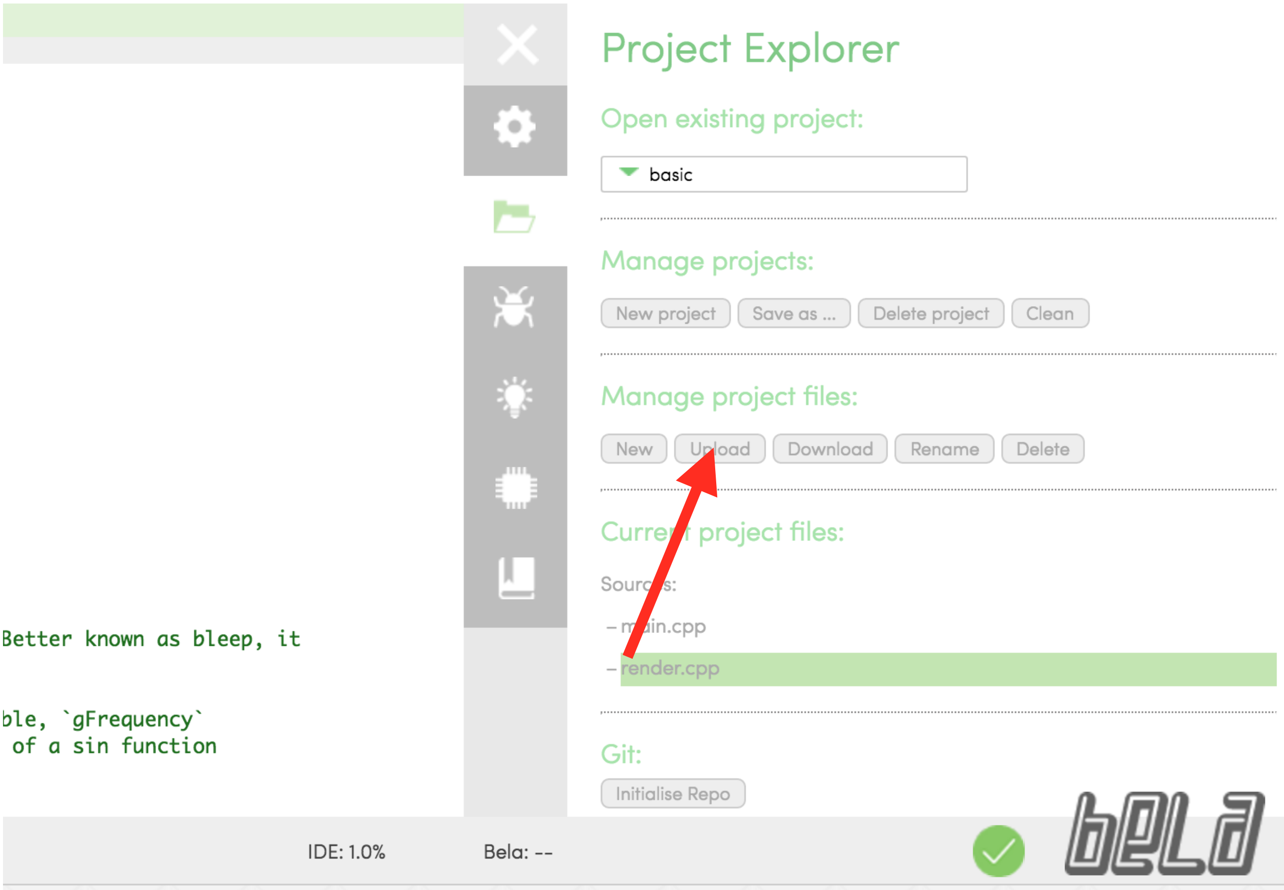

*(for image above, example project open should be **d-box**)*

## Upload D-Box sound files

The D-Box takes sound files in a special .dbx format which contains an analysis of the frequencies and amplitudes of the main sinusoidal partials in the sound. This analysis is generated using the program *SPEAR* by Michael Klingbeil: *http://www.klingbeil.com/spear/* The D-Box can also read raw SPEAR files as described in a separate guide.

Download the default D-Box sounds from the **sounds** directory in the D-Box repository: *https://github.com/BelaPlatform/D-box*

In the *Files* tab of the Bela IDE, under *Manage Project Files*, upload each of the .dbx files into the project folder.




Once the project has been created and the sound files uploaded, click the *Run* button in the lower-left corner of the window. It should compile the source files, which will take a couple minutes, and then run the D-Box program. Provided everything is wired correctly and the sound files are in the directory, the D-Box should now run!

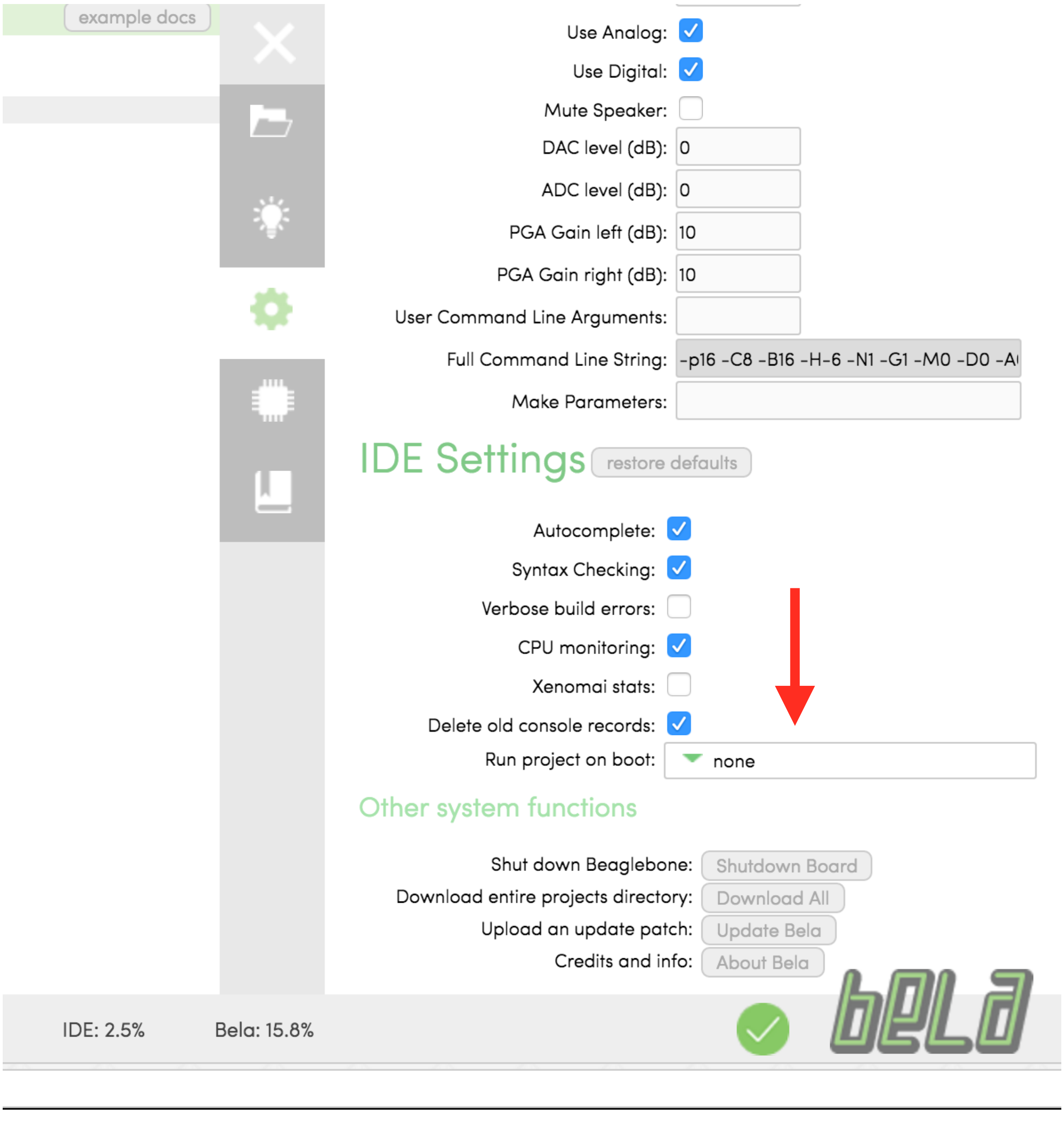
To hear anything from the speaker, you will need to have the board powered from the **USB barrel cable**. If the battery is charged, click its button to power it up. If it isn't charged, you can test it by attaching the USB barrel cable to another free USB port on your computer. (You can still use headphones even if the board is powered only from the mini-USB cable.)

When you run the code, the LED in the back panel should flash rapidly at first, and then slowly after a few seconds. The rapid flashing indicates that the sound files are loading; the slower flashing indicates that the files have finished loading and the D-Box is running. If the code is running but you don't see the LED flashing, check the wiring of the LED.

**Make the D-Box code run on boot**

Go to the *Settings* tab in the sidebar. At the bottom of the tab is a drop-down menu of projects to run on boot. Select *d-box* (or the name of your saved project) from the list. At this point, the D-Box software should launch automatically each time you power up the BeagleBone Black.

Whenever you are finished with the D-Box, you can power it off by holding down the button next to the audio input on the cape, selecting *Shutdown Board* from the *Settings* tab of the browser, or (less ideal but still fine) simply unplugging it or turning the battery off.



## Playing the D-Box

The D-Box is designed to be a deliberately simple and constrained instrument whose behaviour can be modified and hacked by rewiring the internal circuits.

In the normal mode of playing, the two touch sensors on the top of the box control the sound. The sensor further from the speaker starts the sound and controls the pitch. The sensor closer to the speaker acts as a filter. (If you touch only the filter sensor, nothing will happen since the pitch sensor needs to be activated first.)

The sensors are each multi-touch, sensing up to 5 simultaneous fingers. On the pitch sensor, the most recent touch controls the pitch. On the filter sensor, multiple touches produce multiple bandpass responses.

The pitch sensor is pressure sensitive. Pressing harder will make the sound louder.

## Inside the D-Box

Opening the side panel of the D-Box will reveal the *matrix*, a network of analog circuits which can be rewired and hacked to change the operation of the box. It is safe to make any alterations you like to these circuits without damage to the D-Box. (The only known wiring that will cause the box to shut down is to short the speaker terminals together, but this should not cause lasting damage.)

The sounds obtained from rewiring the matrix are often unexpected and glitchy, but the behaviour is never random! The same wiring should repeatably produce the same sounds.

To get started, two places to explore are the blue potentiometer on the breadboard, which will select between several sound clips, and the brown analog input (bottom half of the breadboard), which controls the pitch. In the latter case, touching the brown input wire to different parts of the breadboard will produce different pitches and effects.

A separate manual provides information on hacking the D-Box and loading new sounds.