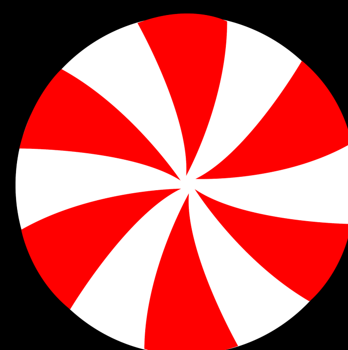
Jack and Jill

An Engineering Story.



Serenity Baruzzini

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Thanks to

-

Braskem

Sal Desantis

John Kamal

Max Lawrence

Calvin Mustokoff

Phil Ryskalczyk

David Ryskalczyk

Asher Swartz

The White Stripes

Every mentor, teammate, classmate, and friend that believed in this.

Biography.

Serenity Baruzzini is a Class of 2020 student, graduating from Science Leadership academy. She was in the CTE engineering program and was Captain of the FRC team, 4454. She spent most of her time at robotics, but could also be found playing Magic the Gathering or video games with friends. She is now going to Drexel University as a mechanical engineering major. While she is unsure of what lies on the road ahead, she aspires to be a high school engineering teacher someday, taking inspiration from her own engineering teacher and mentor, John Kamal.

If you have any questions, feel free to contact her at serenityb223@gmail.com

Foreword.

You may find the table of contents particularly useful in this document. It’s a rollercoaster ride of personal narrative, engineering analysis, and advice. This isn’t what it was intended to be, but it is what it was destined to be. I hope you find it useful to you in any way. Knowing that this project did something for someone makes it that more special, and sharing my story with you is an honor.

Meet Jack and Jill.

My childhood was colorful for the most part. I was homeschooled by my mom, and I spent most of my days with her. Many of my toys were from the 80s and 90s, or my mother made herself.

That’s where the Furby comes in.

I owned a zebra print, striped, 1998 Furby, that was eventually lost in the basement as I grew up. It wasn’t until recently that I fell in love with Furbies again. Here’s the funny thing: when I purchased the Furby for this project, I had no memory of what the one from my childhood looked like. When my mom saw my newfound friend, she was surprised to see the same one I once owned.

I knew that for my senior project, I wanted to incorporate a 1998 Furby. Not only did my love affair start over the obvious cuteness of the animatronic toy, but the robotics behind it. I fell into an internet wormhole of Furby-related facts, controversy, history, and how it is an epic engineering muse.

Originally, I wanted my senior project to revolve around music. I battled with several ideas: 3D printing and laser cutting records, building a record player from scratch, building an instrument. Determined to keep this aspect of myself in the project, I tried to find ways to relate the two. The project I came up with was more personal than I had ever planned.

When I was eight years old, my father died a tragic death. It left my family broken. A key part of my father was his love for music. He had a diverse taste in music, and spent many years as a DJ. Following his passing, I inherited his vinyl collection. Not only that-- I inherited the actual turntables he used when he was alive. I made sure I listened to records, even the ones I didn't like, and tried to teach myself how to scratch. It was a way to connect with my father that I didn't have before. I soon found that I didn't really like it, nor was I good at it. As any kid would, I moved onto things that I found more interesting. Nonetheless, I kept the records and kept listening to them. To this day, a turntable and a box of records sit in my bedroom, a combined collection of both his and mine.

This is what brought me to this project. Using my passion for engineering and robotics as fuel, I brought two parts of my childhood together in something that would bring me joy. In this way, I'm still able to pay homage to my dad. I chose to build a record player from scratch and connect its electronics to the Furby. The icing on the cake was I chose one of my favorite artists to honor in the process.

The White Stripes is an alternative rock band that formed in 1997 in Detroit, Michigan, where my mother grew up. The members included Jack and Meg White, where they made music until 2011. I grew up with the band, and the break up broke my heart. According to them, they stopped making music because they wanted to end on a high note. Jack continued to make music in other bands, such as The Dead Weather and The Raconteurs. He also owns a record label, Third Man Records, where they press vinyl on-site in Detroit.

By naming the Furby "Jill," and naming the project "Jack and Jill," I'm honoring them and the music they made in hopes to preserve their art within my own.

In the course of the project, I realized that the joy didn’t have to end with my completion of the record player. In the same way it brought different parts of myself together, and different types of engineering, it brought people together. I send a million thank yous to everyone who helped me, and by putting together this manual, I want to pay the learning forward.

I hope that this project incites joy and curiosity in you, that you learn new things, that you spend time with people that you care for, and that you make this project your own. Break the rules, design your own machine, but feel free to use my path as a guide for your own.

With this as my final project before I go off to college, I wish the best and leave this behind for you. This is for engineers, FRC students, SLA students, any student that wants it.

This is for you.

x Serenity

January 29th, 2020.

Resources.

Below is a list of resources I used for prior research, which I encourage you to use and reference them as I did throughout the project.Of course, I Googled countless things along the way, but a good way to such a project on its feet is to frontload a lot of research. :)

"Anatomy of a Turntable." *Record Player Pro*, 16 Dec. 2019, www.recordplayerpro.com/anatomy-of-a-turntable-a-beginners-guide/.

This guide provides a description of different turntable elements. It covers basic and advanced mechanisms and pieces of the turntable to different degrees, which gives the reader an idea of what each part does and why. When designing my turntable with Furby electronics in mind, I'm using this to determine how I want to build it.

Eggert, Wayne. "Furby Hacking 101." *Techdose.com*, 20 Sept. 2020, www.techdose.com/projects/Furby-Hacking-101/260/page1.html.

This is another source in the form of a blog. Within the blog, there are references to other sources in this bibliography broken down by type and function. There's also a simplified breakdown of the electronics and how they are applied to different functions. The resources provided are helpful, and the breakdown described is helpful in

identifying which areas of the schematic I need to focus on based on the desired results.

"Consumer-Made Schematic of Furby Electronics."

This was a schematic that can be found in many places online in the form of a PDF. It was created by a man named Chris, based on the early electronics used in the Furby while under ownership of Tiger electronics. I'm using this as a resource for accessing the intended parts of the Furby I need to reprogram.

"Furby Autopsy." *Furby Autopsy*, Phobe.com, 1998, www.phobe.com/furby/index.html.

This website has many moving parts, including sections on how to remove the skin from your Furby and hack it. It's a basic website made by a consumer in the form of a blog. It's been used for the initial deconstruction of the Furby and the plan for how to re-skin it.

Hampton, Dave. *INTERACTIVE TOY (FURBY.ASM - Version 25)*. Sounds Amazing!, 1998.

This is leaked source-code from the original 1998 Furby. It was made open-source in the form of a PDF. This piece existed before any publishing or officialization of the toy, therefore it was not yet bought by Tiger Electronics.

Heaton, Kelly. "Reflection Loop." *Anatomy of the Furby*, 2000, alumni.media.mit.edu/~kelly/Furby/anatomy.htm.

This is the site where all of the exploded drawings of the Furby’s mechanisms can be found. While it doesn’t provide any electrical descriptions, it’s a useful tool for mechanical repair. The drawings were done by an MIT student as a more artful approach to the Furby’s interior, but is still accurate.

Hughes, Matthew. “Take a Look inside the Furby's Leaked Source Code.” *The Next Web*, 13 Aug. 2018, thenextweb.com/dd/2018/08/13/take-a-look-inside-the-furbys-source-code/.

This article provides valuable information on the evolution of the Furby electronics, and leads you to the document that includes the leaked source code for the toy. This is how I initially found the source code and learned about the chipset used in Furby.

Instructables. “DIY Record Player.” *Instructables*, Instructables, 27 Sept. 2017, www.instructables.com/id/DIY-Record-Player/.

While the record player design is not a replica of the one featured here, this was the initial resource for how to start building a turntable. The one featured here is a simple, accessible design. While it’s functional, it can be further developed.

Instructables. “Control a Furby With Arduino (or Other Microcontroller).” *Instructables*, Instructables, 1 Nov. 2017, www.instructables.com/id/Control-a-Furby-with-Arduino-or-other-microcontrol/.

This Instructables describes how to replace the Furby's original motherboard with your own electronics, while leaving the other abilities intact. Since I only wanted a few abilities to work, I needed to do this, regardless of whether the other electronics could remain untouched. This was a starting place to investigate what had to be changed.

Instructables. "Furby Brain Surgery." *Instructables*, Instructables, 1 Nov. 2017, www.instructables.com/id/Furby-Brain-Surgery/.

This is written by the same person that wrote the Instructables about how to incorporate an Arduino in the Furby electronics. It gives a more detailed explanation on how to access the motherboard within the Furby before you can alter it, which is essential if you want to change anything about the electronics.

Nussey, John. "How to Spin a DC Motor with the Arduino." *Dummies*, Wiley, www.dummies.com/computers/arduino/how-to-spin-a-dc-motor-with-the-arduino/.

This article is a basic tutorial on how to connect a motor to an Arduino. It includes what you'll need, along with steps described to make it work. This aspect is surely needed for the record player's function, but might be useful depending on what is chosen to do with the Furby's functions.

Youngblood, Tim. "How To Control a DC Motor with an Arduino - Projects." *All About Circuits*, 7 July 2018, www.allaboutcircuits.com/projects/control-a-motor-with-an-arduino/.

Along with the other source mentioned, this article provides more information on controlling a motor using an Arduino. It links code that can be used as well if this method is used. This just provides more options for how to incorporate a motor and Arduino where applicable in the project.

Materials.

Note: These can vary depending on the route you choose to take for your iteration of the project. I wrote in comments about the parts I used, but I strongly encourage you to make as many changes as your heart desires. Throughout this guide I mention other tools/supplies I would have used with the means to do so.

⅛ inch plywood ⅛ inch acrylic	These are the materials I lasercut for the housing/structure of the turntable.
¼ - 20 bolts 10 - 32 bolts 6 - 32 bolts	I used different size bolts depending on what I was fastening. Standardizing the bolt type is a good practice, but go ham.
Arduino Uno (2)	I used two Arduinos, one for the Furby and one for the motor. Any knockoff brand, including SparkFun or Elegoo will work too. I had some fears about running both on different power sources and through the same Arduino. I'm sure it's possible, so it's up to you.

1998 Furby	This is the fun part! Choose your own little baby! I will give a word of warning: different Furby generations have different guts. 1998-2000 Furbies are similar enough to each other mechanically and electronically. They're easier to work with than later generations because there are more visible parts. I'm unsure about Furby Babies, so proceed with caution and research.
Lubricated turntable	While I purchased my own, you may salvage a record player-specific turntable.
½ inch bearings	Bearings are your friend for anything rotating! In my initial designs I included more spaces for bearings than I knew I needed just in case I wanted an additional component to rotate.
paints	Since a lot of the housing for the turntable was wooden, I really made it my own by giving it a little makeover.

electrical wire	I used 22G wire, but really any wire you'd prototype with works.
soldering iron	Electrical tape will only hold your wires together for so long.
electrical components	The details here will change depending on your choices in circuits. Choose your circuits, then gather your materials.
speakers	I bought really cheap speakers off of Amazon. They were less than $10 for the pair. You could have speakers built into your design, or plug the turntable into seperate speakers if you want a higher-end sound without the commitment.
RCA cables	These are for connecting the preamp and amp. They aren't necessary if you have a different or premade setup.
preamp and amp	I kept these as two separate entities, although you can get a combined version.

phono cartridge

This is the need that goes onto your tonearm. You may want to get one that is for the same turntable as your tonearm (if you get a prebuilt tonearm,) unless you’re making it yourself. Otherwise, you’ll have an ugly solder at the end.

tonearm

I had the most fun designing a tonearm, but I ended up buying one anyway. This is the most challenging component to build yourself because of the technicalities, and I could have spent the whole time on just this piece.

The Wonderful World of Problems.

Yes, another unexpected monologue-- brace yourself. This is where the user's manual should begin, but the world had different plans for us.

I have to say, this school year was rough around the edges. At the end of my Junior year, my school lost the lease on our building. There was no gym, no real cafeteria, and there were apartments on the fourth floor and in the basement. The building was very old, and had gone through many phases of use. It was a factory at some point, offices, apartments, you name it. The building itself was pretty magical. For thirteen years, thousands of Science Leadership Academy students were able to grow up in the building and its dysfunctional grace.

The freight elevator, only really ever used for deliveries and moving the robotics team's stuff, was one of my favorite parts. It was so old, and it felt like it could break at any given moment. It was charming. There are so many parts of that building that were dented by the robotics team, so many holes in the ceilings and walls. All of it was homey and felt like no other school I had ever been in.

But that was my final year. Our final year. We were uprooted and placed in the same building as Benjamin Franklin High School. One large school building, divided by a glass wall in the middle. While our schools coexist in the same location, we never interact. All of this change required a lot of construction,which delayed the opening of the school, as if moving wasn't bad enough. But that was only the start of our problems. Then came the asbestos.

During construction, asbestos was disturbed in the building. It was a safety hazard, so we were doing schoolwork online from home for about a month. When the district finally realized they needed more time to sort everything out, we were relocated to the Philadelphia School District Office Building. Our classes were held in conference rooms, and the lobby became our common area. It wasn't until the end of February that SLA finally moved into the building we were intended to reside in.

Now is a good time to mention that every SLA Senior is required to complete a Capstone, an independent project that lasts the entire school year. I went into my Senior year expecting to just be able to build this Furby/Turntable contraption, having access to a brand new shop and all our machines. I couldn't have been more excited, and even started the research during my Junior year. The project was delayed by six months, leaving about three months for the entire thing. At last, we had an engineering room, a shop. I got to work straight away on working out the kinks and modifying my plan for the project. I knew it would be rushed, but I was determined to make it just as well as I originally planned.

That should be the end of the story. I should have worked my late nights in the shop, machining and designing and building and cutting and laughing and learning. This is not what happened. Beyond anyone's control, the COVID-19 outbreak hit America. In mid-March, school was canceled indefinitely. I got only a few weeks in the shop before I had to spend an afternoon frantically packing up everything I could before we were sent home. I missed a couple parts, I'll admit. I walked out of school with two shopping bags full of my parts, and that was my Capstone.

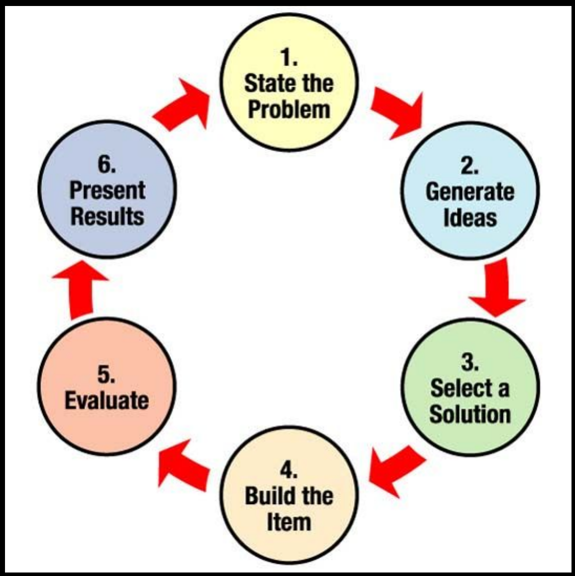
Now, I’m sitting on my bed writing this, still determined to finish this project from within the walls of my bedroom. My dream of having a beautifully machined and constructed turntable is far less likely now, but I am still determined to deliver the best product I can. I’ve come to realize that this document will be the majority of that product. This document was meant to be a functional manual, and I would have revelled in the completion of my creation. Instead, this document is the evidence of what was meant to be, and I’m more than alright with that. what I am using my time in quarantine to pour my heart into everything I wanted my Senior year to be. I might not have prom, graduation, or a shop, but I have this, and you, the reader. This is for you. Please be understanding of the struggle, the chaos, and dysfunction I’m recording on these pages.

Thank you for your time and for believing in this project. You’ve made my Senior year.

March 25th, 2020.

The Engineering Process.

The NASA engineering process is a good place to start.



Every Capstone has an essential question. Mine was, "How can I build something authentic to myself?" While I had the project idea before the question, deriving a question from what I knew I wanted was important for when I got lost. Regardless of what happened, what choices I made, problems along the way, I could always revert back to the question. While the record player may not be finished, my project still hasn't strayed from its purpose.

The questions I found myself asking at first were very broad. Then, I broke the project into segments based on those questions. An example of a broad question is, "How will it produce sound?" From there, I asked questions stemming from it such as, "What's the path of sound from the needle to the speaker?" From such questions, I generated ideas for answers. From this came the first design variations. Waiting until this point to design is important because form follows function. Prior to knowing what to build, I needed to determine the reason for building it as so.

Without much time at my disposal, the whole project became a prototype. While prototyping should always be rapid, the whole design became rapid too. While building each component, I saw issues that would affect another component. Rather than immediately fixing the issue, pausing to understand what went wrong is essential to any design’s growth. While taking this extra time might make everything take longer as a whole, it saves how many variations you’ll have to burn through. That ends up being more frustrating anyway.

Turntable: How to Start.

In complete honesty, you should start by asking yourself one question:

How much work do I want to do?

You could find a record player you like, take it apart, and do your wiring and programming from there. I started with the intention of building as much from scratch as I could. I wanted to purchase a motor, a motor controller, and program it to be the right speed myself. I wanted to build a tonearm from scratch, I even went as far to break down how I would build the pivot point from a 3D printed part and a bearing. Due to the circumstances of the time and machine constraints, I've purchased a replacement direct drive record player motor, as well as a replacement tonearm. The perks of doing it that way is simplification.

One of the most important things I've learned as an engineer is to work smarter, not harder. Before you design or build, decide what you want out of the project. If you want a deeper exploration of a certain part of a record player, then build that part from scratch. If you just want to just make the darn thing, then sure, order a bunch of premade parts.

Perhaps you may choose to do this project in a group of people. I envision that being quite fun, because then you can break down who is responsible for which aspect of the turntable. Everyone gets to learn something different, while still being forced to collaborate and make sure the designs are cohesive. Another perk of doing it in a group is it will cut down on the time needed to complete everything.

Turntable: Direct vs. Belt Drive.

It is well worth your time to research the differences between direct and belt drive turntables. Direct drive is surely simpler, as the motor spins the record directly. There’s room to play there with speed control and consistency.

How do you spin at the right speed?

Are the speeds preset?

Does the user use a potentiometer to control the speed?

How do you choose the correct motor?

What kind of motor controllers are there?

There are a ton of unique problems that come with choosing this route. On the other hand, you could work with belt drive. I chose not to because it felt more complicated. I have had bad belt-related luck in robotics, but that’s a different story. I don’t know much about belt driven turntables, except for that the belt is used for mechanical advantage, smoother sound, and a longer lasting turntable.

Turntable: My Motor.

The replacement motor used was a Sanyo TP1012A model. I purchased it independently from the rest of the turntable, which in itself complicates the process. With it being so old and specific, I was only able to find a newer version's manual online. Nicely enough, there was a schematic for the turntable. This allowed me to build the rest of the circuit around the motor, from which then I could start testing.

This was the fun part: I had to determine the forward voltage needed to make the motor spin at the right speed. I could have used a variable power supply, calibration disk, and a fluorescent light. I was not in a shop. As I mentioned earlier, I had to do this at home. The best I could do was vary the power myself using AA batteries in 1.5 volt increments. To do this, I made a little ½ inch track out of wooden dowels on my bedroom floor. With this track, I lined up AA batteries. 24 volts and 16 batteries later, I lost motivation. realizing that this method wouldn't be nearly accurate enough to get it right, and that I was better off postponing the project until I had a shop again. The motor's neediness was my defeat in this attempt.

Out of this experience, if using a replacement direct drive motor, I'd make the following recommendations:

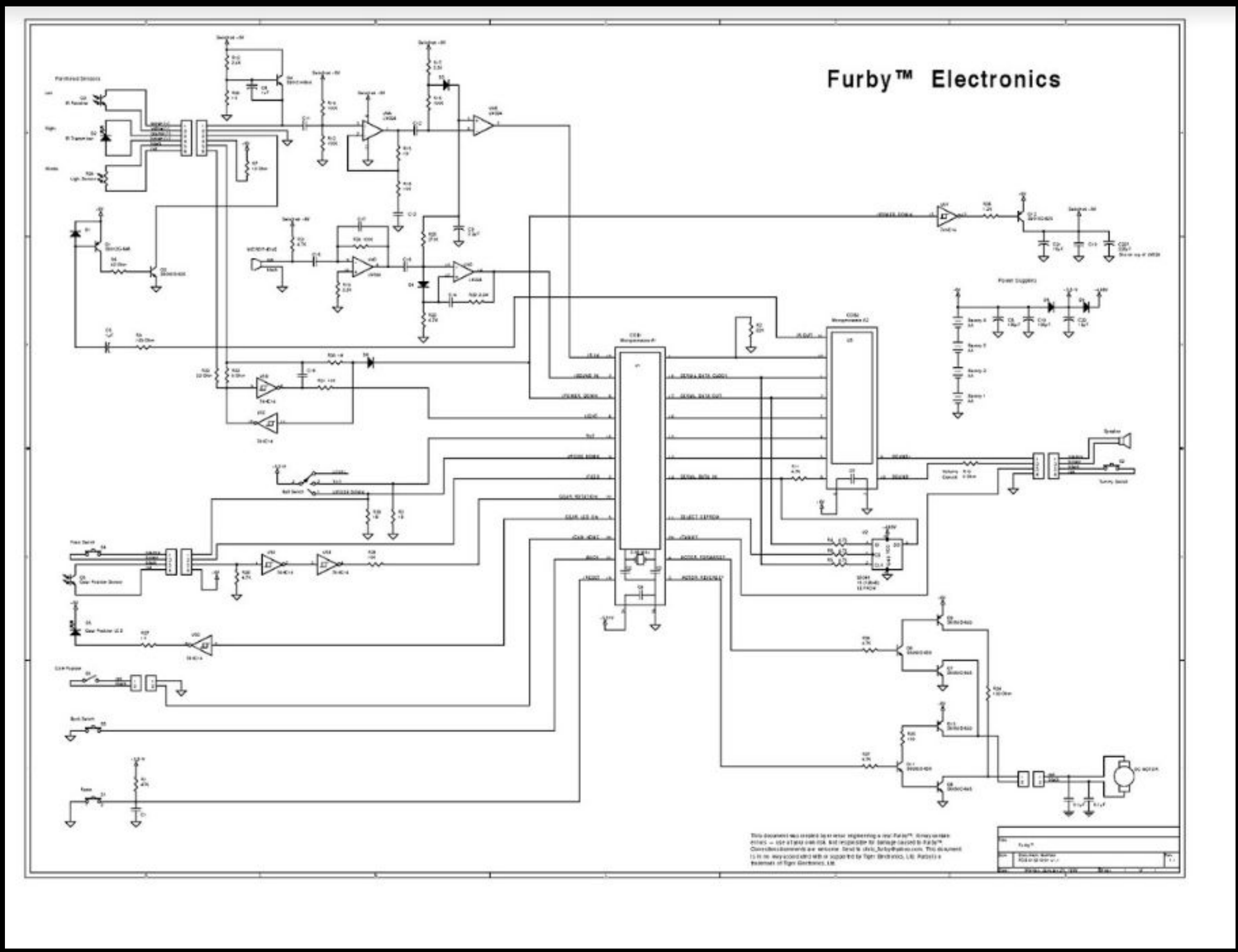
1. Find the turntable's manual!
2. Obtain a schematic
3. Try your best to find the voltage required before committing to said motor
4. Try to take a motor from a scrap record player

Furby: How to Start.

I apologize in advance, but you will need to skin your dear Furby friend. As I said before in my materials descriptions, I recommend using a 1998, 1999, or 2000 Furby. This is because the electronics are the most similar. Out of all the research I've done, the most was done on Furby electronics. There are a ton of online open source resources for the code, schematics, and mechanics. That's why this whole project is built around the thing. This is also where I'll say that with such a vast world of toys, this project is your oyster. Perhaps another animatronic or electronic musical toy is calling your name.

Once you have your Furby, you will need to deconstruct it. I recommend using an Arduino to control the Furby, rather than modify the motherboard. The motherboard is coated in black goop to prevent you from doing so.

Furby Electronics.



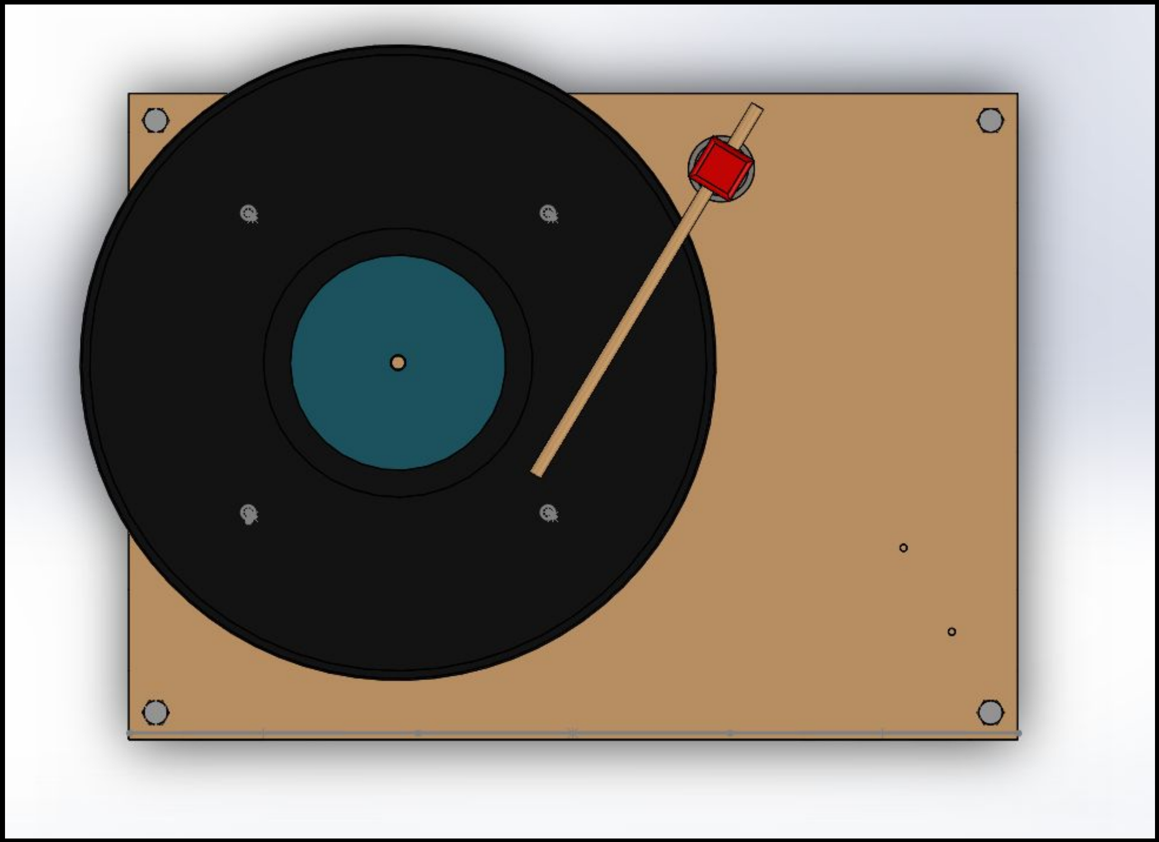
This schematic can be found in the resources section.

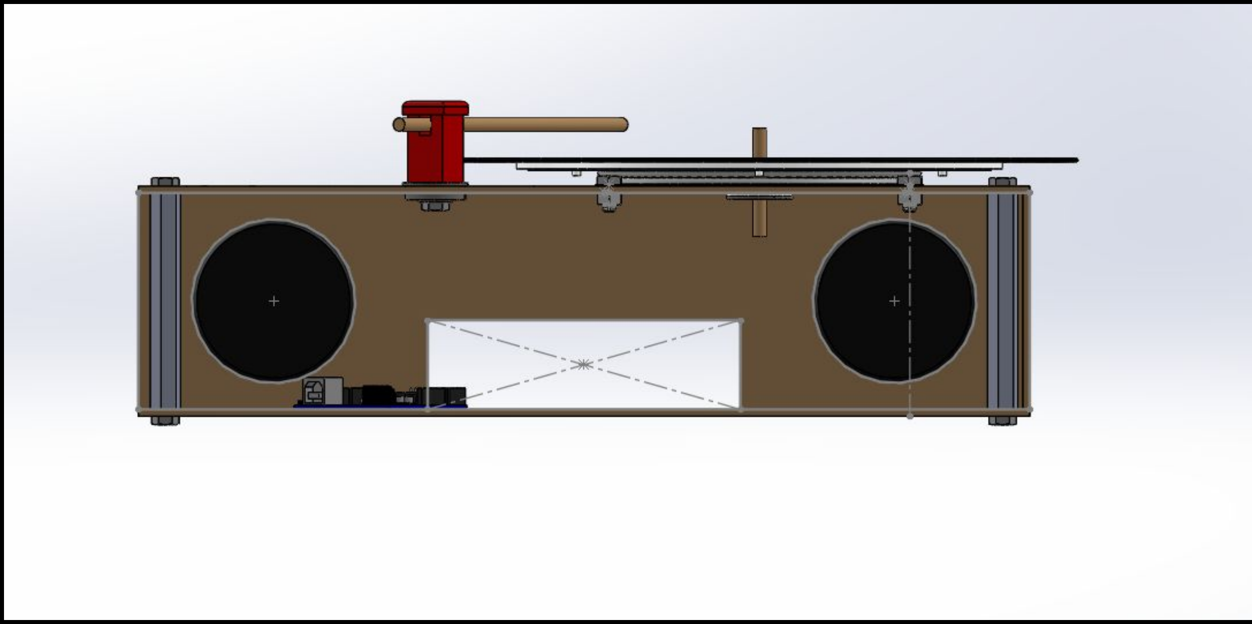
This is the part where your generation of Furby matters. The first few years of production have similar enough insides that the few online resources I could find were applicable. What I mean is that while the schematic above was made for the 1999 Furby and not the 1998 Furby, I was still able to use it. Most of my ability to take it apart came from Instructables I found online, and this schematic was used to decide what I wanted my Furby to do. I sat down and labeled, highlighted, and wrote labels for each section, then pondered the difficulty of manipulating different functions. While this was fun, it’s one of the more involved steps. I found that giving power to one section of wires would cause the eyes, ears, and mouth to move all at once. This was the simplest thing I could manage, which due to my time constraint, I settled on using that ability.

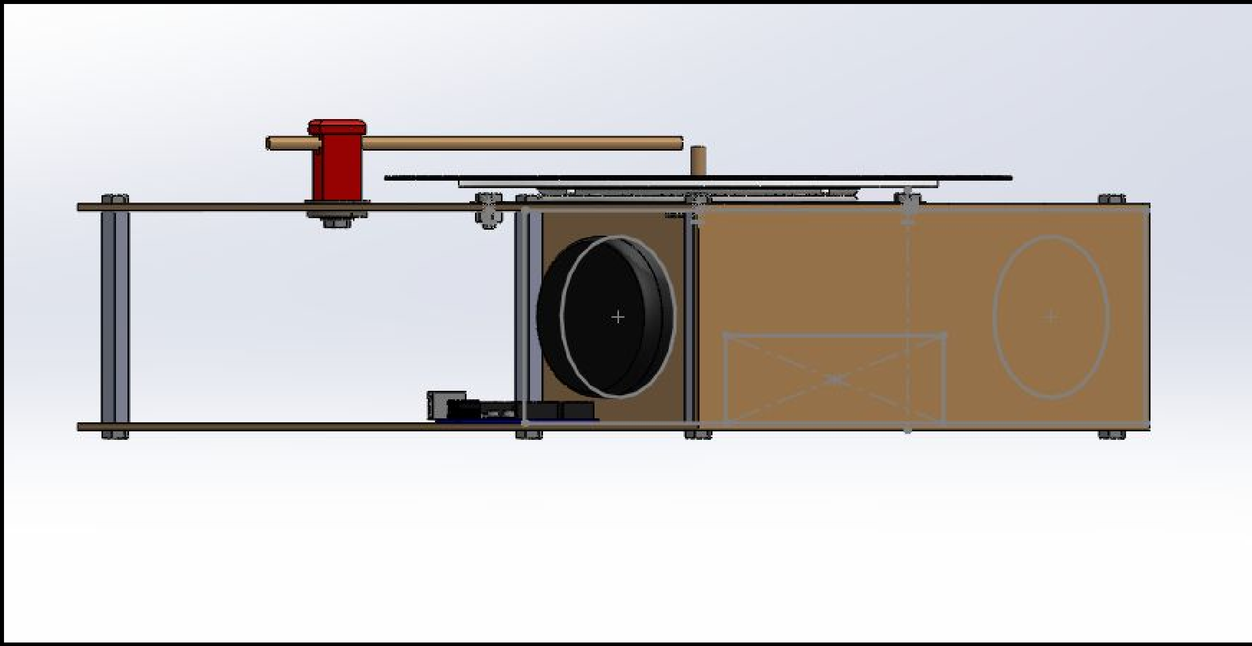
Computer Aided Design.

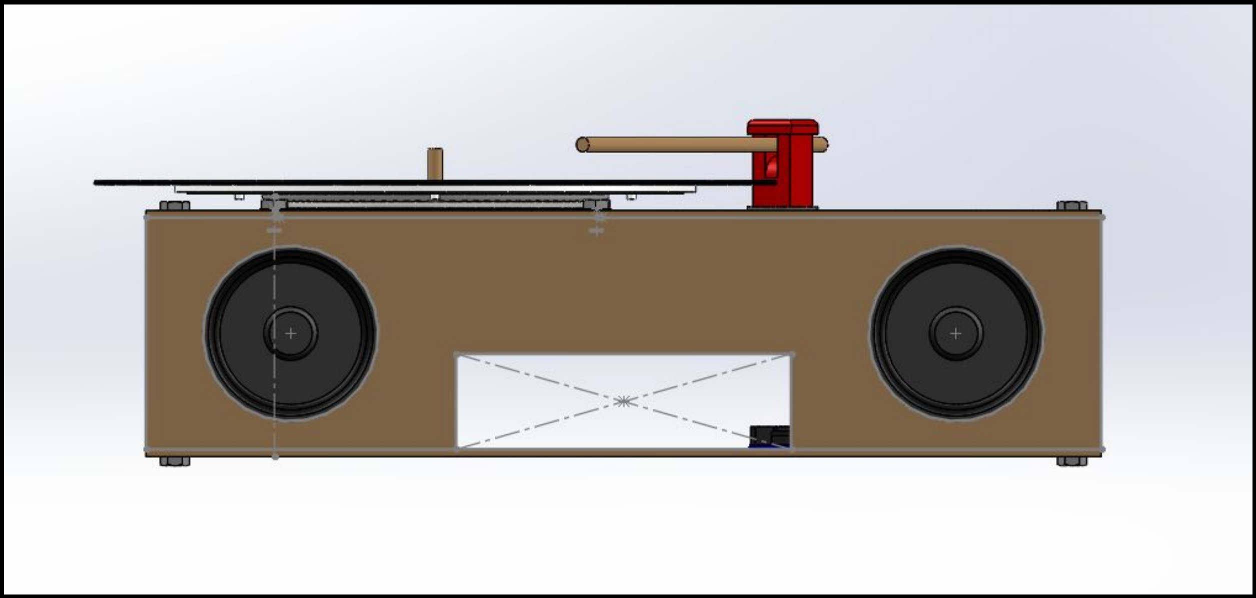
I chose to use Solidworks for the CAD software. All of the CAD was done prior to moving back into the school as more of a conceptual design. A lot of parts were designed to be laser cut or 3D printed myself. The tone arm balancer (red) and the tone arm itself were 3D printed. To make the tonearm, I considered the internal space for the wires, as well as threading on the back for a weight to be screwed on. The tip was designed to have room for the phono cartridge to slide in as well. Ultimately, that tonearm design needed much more work and tweaking, and I realized my time could be spent elsewhere. I ended up getting another premade tonearm model that I would wire up myself.

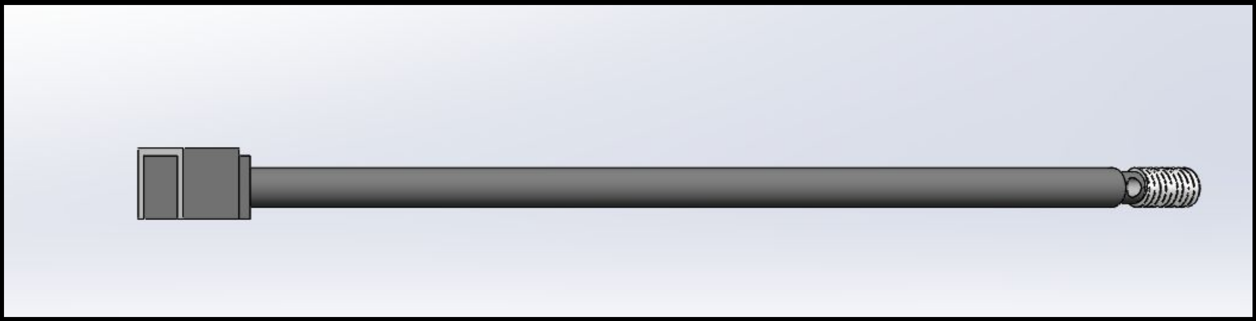
While in the early stages of CAD, I made efforts to use parts that I'm used to working with at robotics. This included certain types of nuts and bolts, as well as bearings.



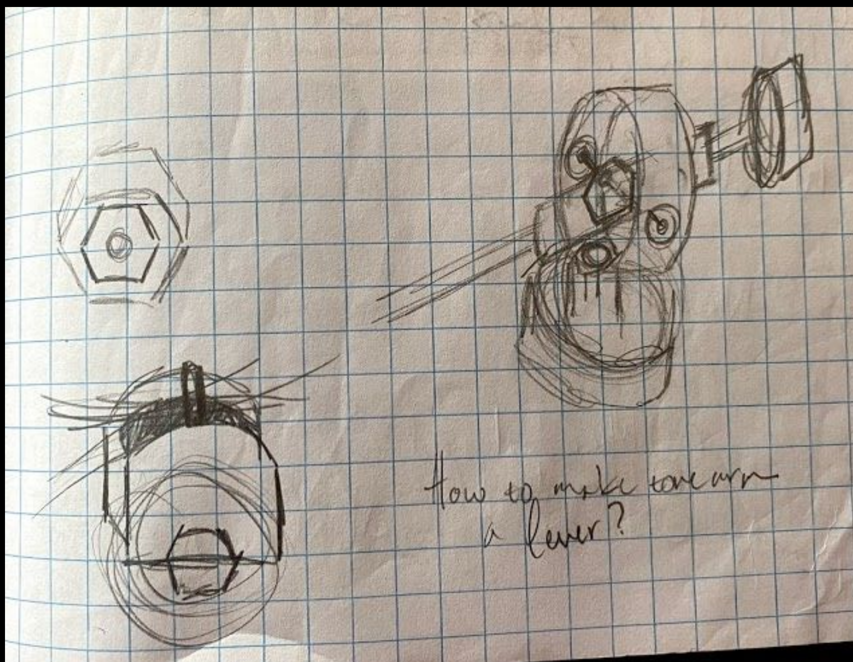


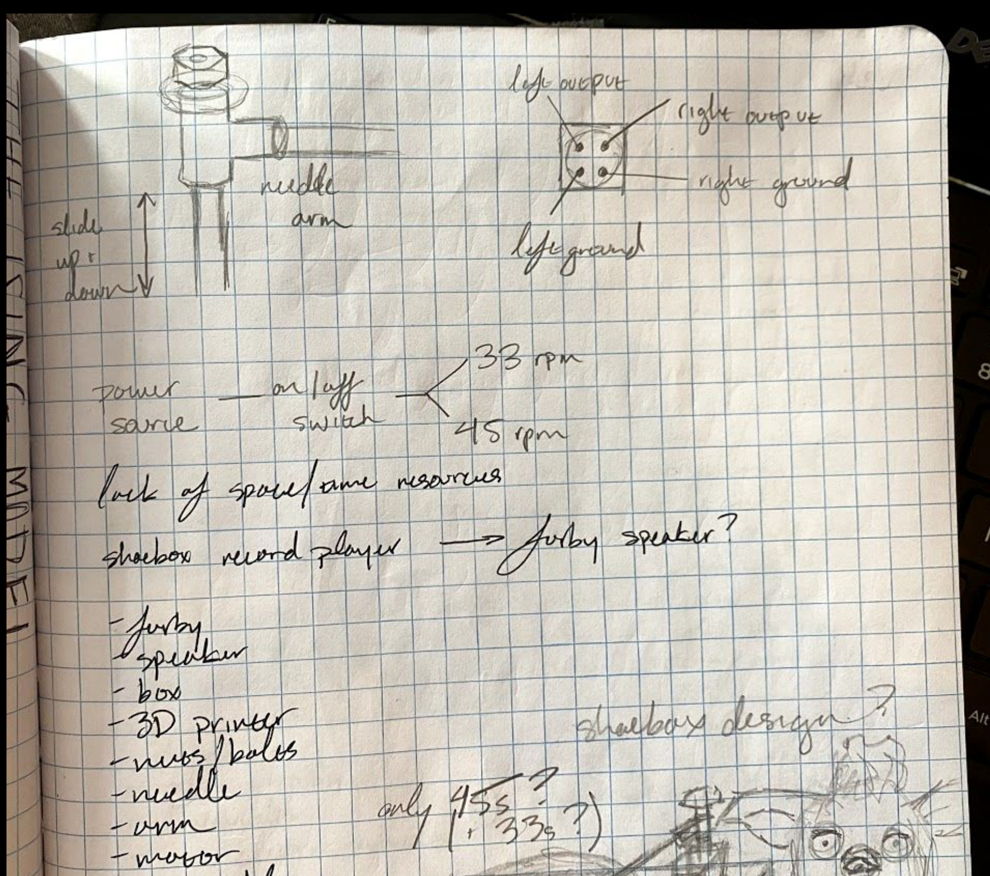


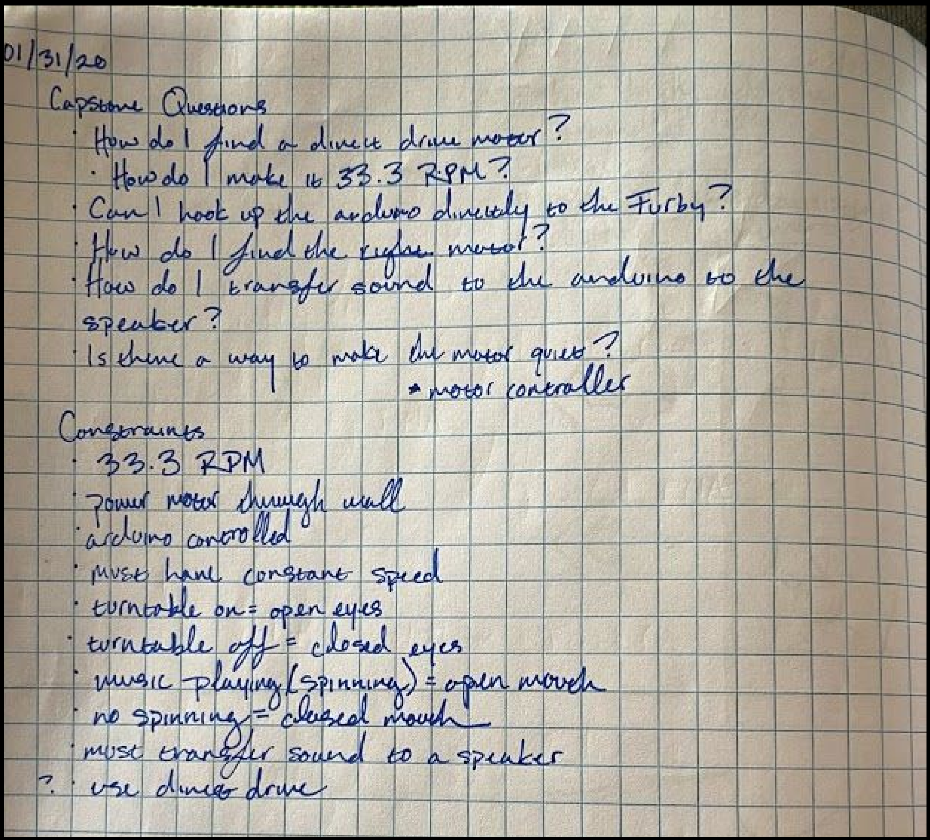




Notebook Snapshots.







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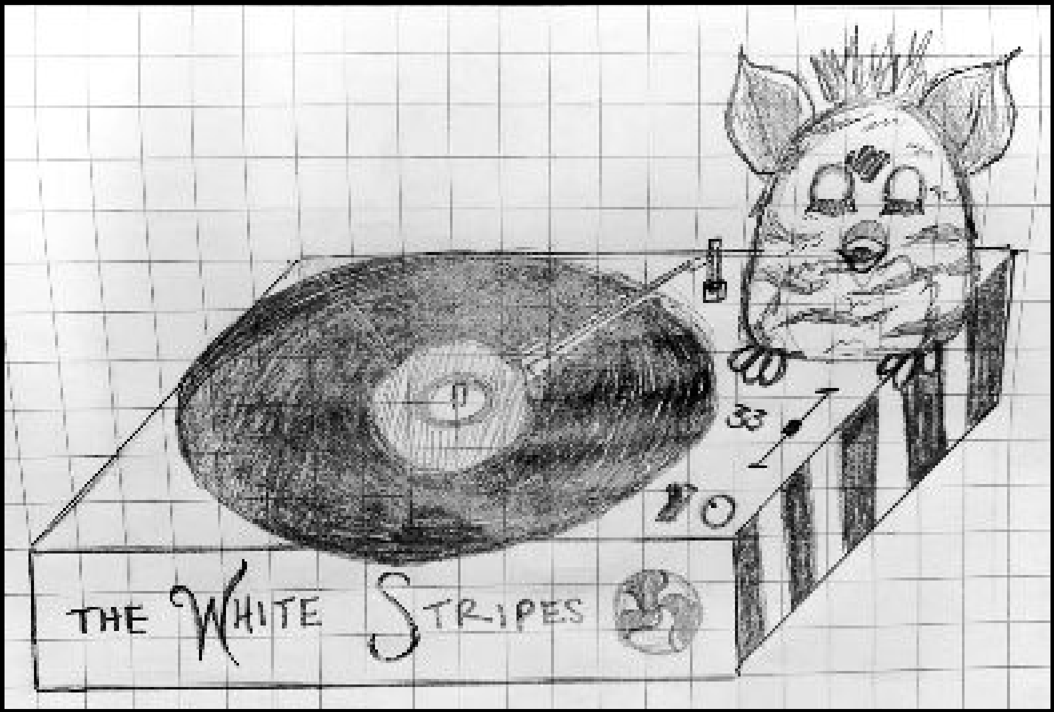
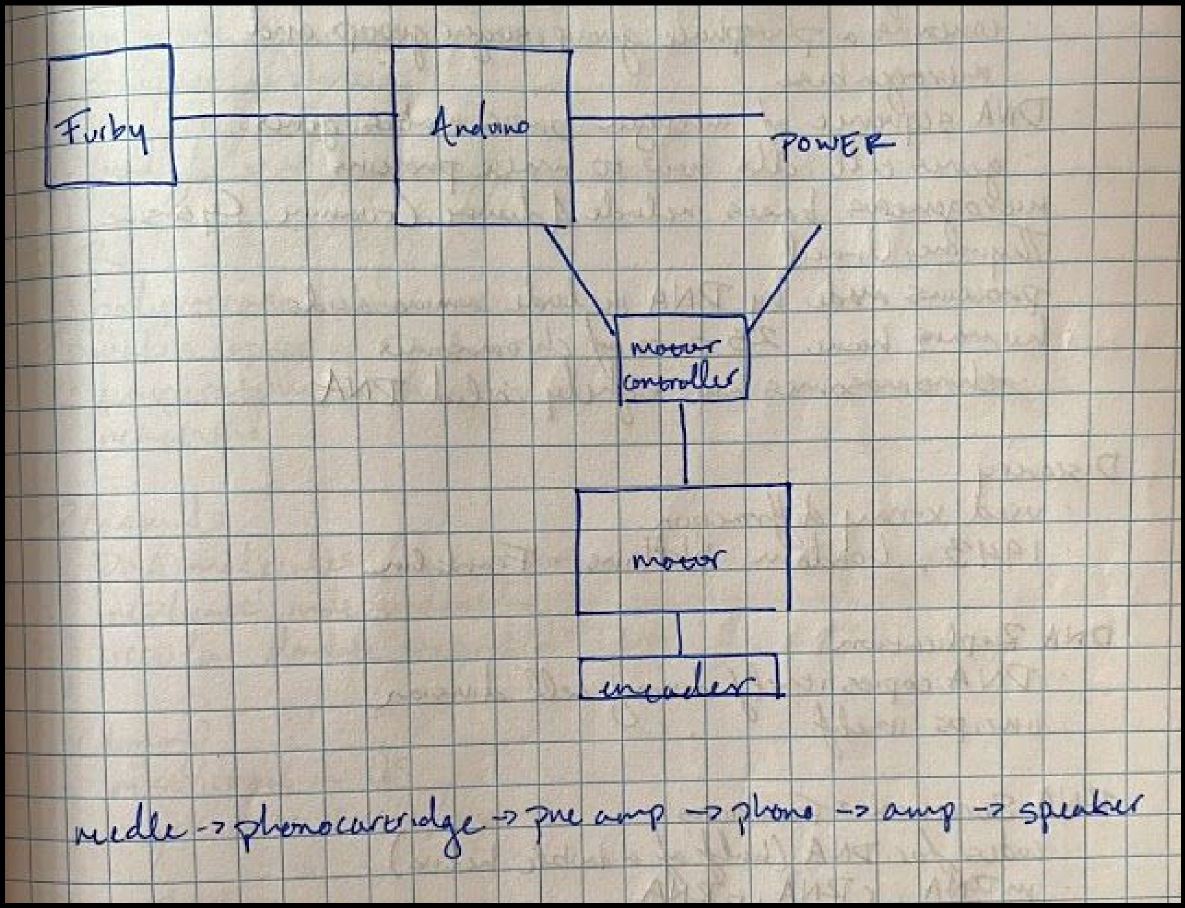
Capstone Questions

- How do I find a direct drive motor?
  - How do I make it 33.3 RPM?
- Can I hook up the arduino directly to the Furby?
- How do I find the right motor?
- How do I transfer sound to the arduino to the speaker?
- Is there a way to make the motor quiet?
  - * motor controller

Constraints

- 33.3 RPM
- power motor through wall
- arduino controlled
- must have constant speed
- turntable on = open eyes
- turntable off = closed eyes
- music playing (spinning) = open mouth
- no spinning = closed mouth
- must transfer sound to a speaker
- ? use direct drive




Furby
Arduino
POWER
motor controller
motor
encoder

Manufacturing and Assembly.

The manufacturing required was 3D printing and laser cutting, which I managed to get done at school. The only proper assembly and manufacturing that was completed was the housing, which was a result of my CAD being done and refined so early. I would have hoped to have more time with the electrical and tonearm components, that way I could have refined the housing more based on my design. At the tie, I assumed I could do those things at home, and therefore prioritized having access to the shop over the order of things getting done.

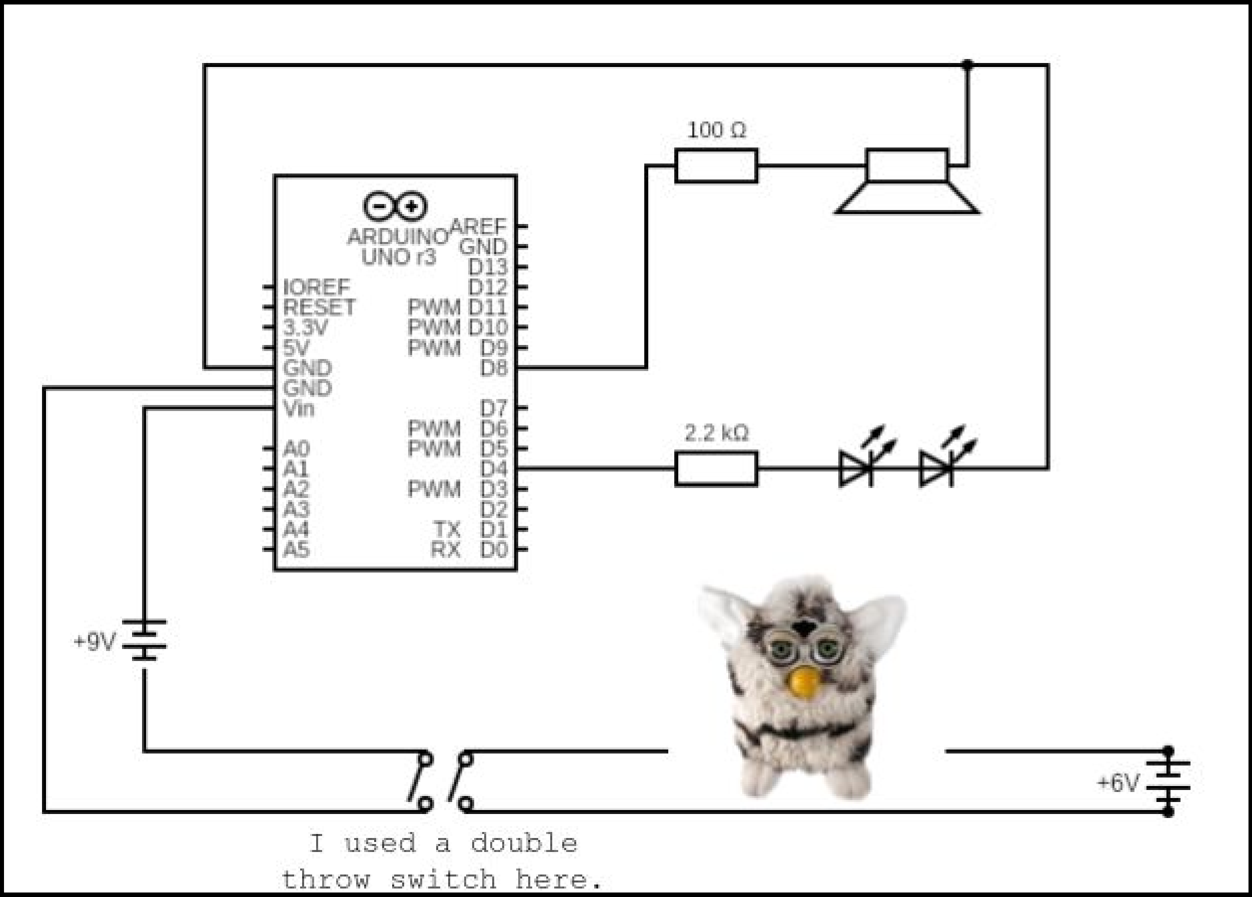
So What Happened to the Final Product?

When I realized that my project wasn't going to make it, I knew I didn't want to waste the materials and effort that had already gone into it. I separated the sections I was confident in, AKA the sound engineering and Furby, and made two seperate mini-projects.

The first of the two was a shoebox-boombox I made using the speakers and amp that was originally for the turntable. I drew out on a shoebox where I wanted the placement of things to be, then cut and assembled. I also painted the thing and added some aesthetic details, including an LED mini circuit. I focused the theme on a song from the Animal Crossing franchise, "Bubblegum K.K."

I wanted to stay true to The White Stripes in the second mini-project, which became the Furby Box. When a double throw switch is flipped, “Fell in Love With a Girl” by The White Stripes starts playing through a buzzer, programmed by an Arduino, lights turn on, and my dear Furby, Jill, flails around. You can find a video of her in action here.

Furby Box Programming and Electronics.



To make the schematic, I used a website called circuit-diagram.org. It's very simple and makes downloading the schematic easy. Most of the electronics design for this came from the Arduino website, as well as what I knew about powering Jill. I didn't include the details on what's happening inside of Jill, since you can reference the Furby schematic that can be found in the resources section.

The following code was made in the Arduino web editor, based on one of the provided examples in their library. The example plays a melody using the arduino, and allows you to change the notes, their octaves, and their timing. You’ll notice some of the code is commented out, which is just how I resolved errors. This is the code I uploaded to my Arduino:

```
const int a = digitalRead(8);

#include "pitches.h"

// notes in the melody:
int melody[] = {
 NOTE_FS5, NOTE_FS5, NOTE_E5, NOTE_D5, NOTE_B4, NOTE_D5, NOTE_0,
 NOTE_E5, NOTE_FS5, NOTE_FS5, NOTE_E5, NOTE_D5, NOTE_B5,
NOTE_FS5, NOTE_E5, NOTE_D4, NOTE_B4, NOTE_0,
 NOTE_FS5, NOTE_FS5, NOTE_FS5, NOTE_E5, NOTE_D5, NOTE_B4,
NOTE_D4, NOTE_0,
 NOTE_D5, NOTE_E5, NOTE_FS5, NOTE_E5, NOTE_D5, NOTE_B5, NOTE_B5,
NOTE_FS5, NOTE_E5, NOTE_D4, NOTE_B4, NOTE_0,

 NOTE_FS5, NOTE_FS5, NOTE_FS5, NOTE_FS5, NOTE_FS5, NOTE_A5,
NOTE_FS5, NOTE_FS5, NOTE_0,
 NOTE_FS5, NOTE_FS5, NOTE_FS5, NOTE_E5, NOTE_D5, NOTE_B5,
NOTE_B5, NOTE_FS5, NOTE_FS5, NOTE_FS5, NOTE_FS5, NOTE_0,

 NOTE_FS5, NOTE_FS5, NOTE_FS5, NOTE_FS5, NOTE_FS5, NOTE_FS5,
NOTE_A6, NOTE_FS5, NOTE_FS5, NOTE_0,
 NOTE_FS4, NOTE_E4, NOTE_E4, NOTE_E4, NOTE_E4, NOTE_D4,
```

```
 NOTE_B4, NOTE_B4, NOTE_FS4, NOTE_FS4, NOTE_E4, NOTE_D4,
NOTE_D4, NOTE_A4, NOTE_A4, NOTE_A3, NOTE_0, NOTE_0
};
// note durations: 4 = quarter note, 8 = eighth note, etc.:
int noteDurations[] = {
 8, 8, 8, 8, 8, 8, 4,
 8, 8, 8, 8, 4, 8, 8, 8, 8, 8, 4,
 8, 8, 8, 8, 8, 4, 4,
 8, 8, 4, 4, 4, 8, 8, 4, 8, 8, 4, 4,

 8, 4, 8, 8, 8, 8, 8, 8, 8, 8,
 8, 8, 4, 4, 4, 8, 8, 8, 8, 8, 8, 4,

 8, 8, 8, 8, 8, 8, 4, 8, 4, 8,
 8, 8, 8, 8, 8, 4,
 8, 8, 4, 8, 4, 4, 4, 8, 8, 4, 4

};

void setup() {
  pinMode(8, INPUT);
  pinMode(4, OUTPUT);
}

void loop() {
  // iterate over the notes of the melody:
 for
 (int thisNote = 0; thisNote < (81); thisNote++) {
digitalWrite(4, HIGH);
```

```
    /*if (a == LOW){
      break;
    }
    else{*/

    // to calculate the note duration, take one second divided by
the note type.
    //e.g. quarter note = 1000 / 4, eighth note = 1000/8, etc.
    int noteDuration = 1000 / noteDurations[thisNote];
    tone(8, melody[thisNote], noteDuration);

    // to distinguish the notes, set a minimum time between them.
    // the note's duration + 30% seems to work well:
    int pauseBetweenNotes = noteDuration * 1.30;
    delay(pauseBetweenNotes);
    // stop the tone playing:
    noTone(81);
    }
}
 /*}*/
```

To go along with it, I needed to make a seperate tab that included the pitches of the notes. That way my main code could reference those definitions. I had to add some of my own that I could use as rests in the song (NOTE_0.) The tab is called, “pitches.h”

This is what that looked like:

```
/*************************************************
```

```
 * Public Constants
 *************************************************/
#define NOTE_0   30
#define NOTE_B0  31
#define NOTE_C1  33
#define NOTE_CS1 35
#define NOTE_D1  37
#define NOTE_DS1 39
#define NOTE_E1  41
#define NOTE_F1  44
#define NOTE_FS1 46
#define NOTE_G1  49
#define NOTE_GS1 52
#define NOTE_A1  55
#define NOTE_AS1 58
#define NOTE_B1  62
#define NOTE_C2  65
#define NOTE_CS2 69
#define NOTE_D2  73
#define NOTE_DS2 78
#define NOTE_E2  82
#define NOTE_F2  87
#define NOTE_FS2 93
#define NOTE_G2  98
#define NOTE_GS2 104
#define NOTE_A2  110
#define NOTE_AS2 117
#define NOTE_B2  123
#define NOTE_C3  131
```

```
#define NOTE_CS3 139
#define NOTE_D3  147
#define NOTE_DS3 156
#define NOTE_E3  165
#define NOTE_F3  175
#define NOTE_FS3 185
#define NOTE_G3  196
#define NOTE_GS3 208
#define NOTE_A3  220
#define NOTE_AS3 233
#define NOTE_B3  247
#define NOTE_C4  262
#define NOTE_CS4 277
#define NOTE_D4  294
#define NOTE_DS4 311
#define NOTE_E4  330
#define NOTE_F4  349
#define NOTE_FS4 370
#define NOTE_G4  392
#define NOTE_GS4 415
#define NOTE_A4  440
#define NOTE_AS4 466
#define NOTE_B4  494
#define NOTE_C5  523
#define NOTE_CS5 554
#define NOTE_D5  587
#define NOTE_DS5 622
#define NOTE_E5  659
#define NOTE_F5  698
```

```
#define NOTE_FS5 740
#define NOTE_G5  784
#define NOTE_GS5 831
#define NOTE_A5  880
#define NOTE_AS5 932
#define NOTE_B5  988
#define NOTE_C6  1047
#define NOTE_CS6 1109
#define NOTE_D6  1175
#define NOTE_DS6 1245
#define NOTE_E6  1319
#define NOTE_F6  1397
#define NOTE_FS6 1480
#define NOTE_G6  1568
#define NOTE_GS6 1661
#define NOTE_A6  1760
#define NOTE_AS6 1865
#define NOTE_B6  1976
#define NOTE_C7  2093
#define NOTE_CS7 2217
#define NOTE_D7  2349
#define NOTE_DS7 2489
#define NOTE_E7  2637
#define NOTE_F7  2794
#define NOTE_FS7 2960
#define NOTE_G7  3136
#define NOTE_GS7 3322
#define NOTE_A7  3520
#define NOTE_AS7 3729
```

```
#define NOTE_B7  3951
#define NOTE_C8  4186
#define NOTE_CS8 4435
#define NOTE_D8  4699
#define NOTE_DS8 4978
```

SLA's Core Values.

Inquiry	My guiding question for the project was, "How can I build something authentic to myself?" The whole Capstone was inquiry-driven. As each problem arose, with it came more questions that guided my progress as I searched for answers.
Research	Since I had so much time prior to the few weeks I had access to a shop, a lot of research went into it. I wanted to be as prepared as possible to get moving. Research came in the form of a lot of reading online resources, as well as fleshing out the concept myself.
Collaboration	A lot of engineers, alumni, and peers were interested in being a part of the project. A lot of advice and knowledge came from them. Since the project's end goal was this document, being

able to ultimately share it was highly valued.

Presentation

This document, as well as the bits and pieces showcased on my Instagram (@freakinmackerel) were the vessels to share the project with the world.

Reflection

This document within itself was the overall reflection. So much of it became a personal narrative of my experience as a student and engineer during this time. The reflection points became more valuable than the completion of the physical product itself.

A Word of Advice.

Engineering is hard.

I spent most of my high school career believing I was stupid. It felt like anything I designed failed, and no matter how much time and effort went into it, I was still lacking. This overflowed into my more difficult math classes as well, and especially in our Robotics Club. Every day I exuded confidence and came prepared, but that was surface deep. Maybe this is about high school being hard, too. Either way, things get hard. We learn to adapt to change, because that's what humans do. I don't know how my senior year of high school could have gone worse, if you've read this far, you understand. I can sit here and feel sorry, guilty, and resentful about the series of events that occured this school year. And I do. But that doesn't help me.

I'm one of those people, along with most engineers, who just love to be busy. I drive myself crazy with how much I commit to doing, and if I don't have something to stress over, I'll find something. Being on overdrive up until quarantine made me too nearsighted. One of the most powerful things I've learned this year is to remember to observe the world from 1000 feet high. Being able to disconnect yourself from a situation to change perspective is hard, but valuable, and it can be applied in any situation. That's where we can learn the most about ourselves, our relationships, and how we interact with the world. Being forced to hit the brakes by staying home gave me the chance to breathe and take a step back. That is when I learned the most about this project, myself, and what it means to be an engineer.

It's easy to feel failure when you're gauging worth on productivity and finding correct answers, and it made me a miserable person. Every failure felt like defeat. I always got back up and tried again, but behind closed doors I was constantly questioning my abilities in this field of study. At the end of the day I made something beautiful for this project. I followed the engineering process, and it took me on a hell of a ride. While this project didn't go as planned, it was meant to be a learning experience, and in that sense I feel accomplished. Even my guiding question of, "How can I build something authentic to myself?" was still answered. Everything I ended up doing was authentic because it was real, raw, and a product of the joy and pain I've endured while doing what I love.

Enough about me.

This is for you, too.

Engineering is about failure, learning, and building people up. For too long it's been taught as a study that can be kept in a box, but people who do real things and change the world know how to trust their intuition. Don't gauge your worth on productivity, but what your intentions are and your determination to make a change. As long as you are either being your best or admitting when you're not, progress is made. Using your compassion to drive something larger is a beautiful thing. Lastly, know when to say no. Know your limits, when your health is on the line, or when a deadline is unreasonable. Being self aware enough to question decisions that will hurt you or others is important. In this project, there were both times of doubt in biting off too much and too little. Just find what they are.

Failure is as important as success, and how you move with it determines who you are. Engineering is about perseverance and change, and working through these challenges has been a pleasure. Be thankful for those who are willing to stand with you, against you, and help you grow. Know your worth, and know it well. I hope this project means something to you. It meant a lot to me, and this is my salutation to the end of high school.

Cheers to that.