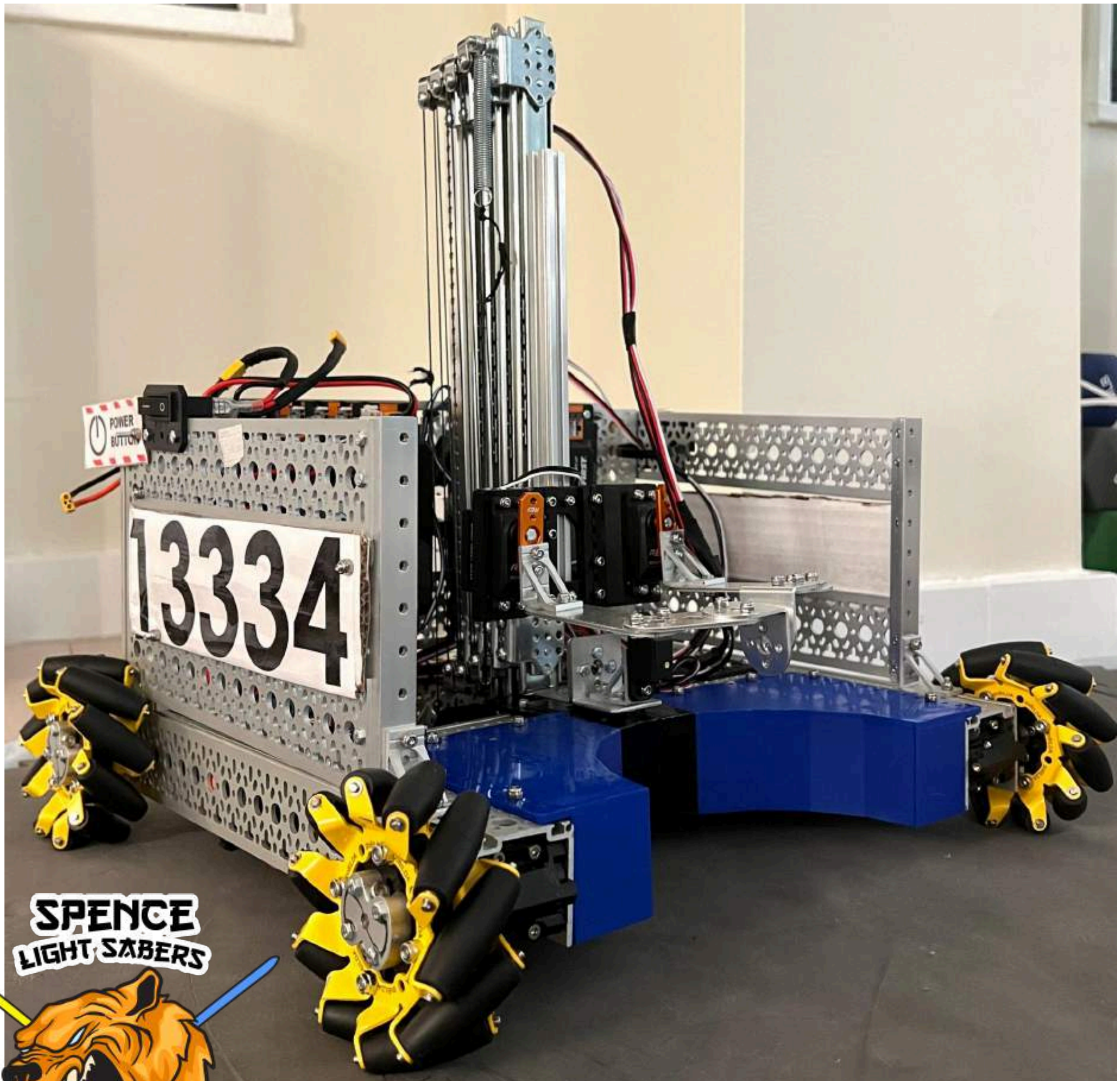
Engineering Portfolio

2022 - 2023



SPENCE LIGHT SABERS

13334

Team 13334

Meet the Spence Light Sabers!

The Spence Light Sabers is an all-girls robotics team from The Spence School, an independent school in New York City. Our team was founded by four eighth grade students who sought to explore their growing interests in engineering through robotics. Although most of our founding members had previously dedicated a significant amount of their time developing their skills in creative fields such as visual art or dance, they were all passionate about creating a space for women to voice their unique perspectives in STEM related fields and confidently apply their existing skills to the engineering process. In 2018-2019, our team accepted the challenge of competing in Rover Ruckus. Despite our limited membership and prior experience with FIRST Tech Challenge, our team successfully advanced to Superqualifiers and gained valuable insight in designing, building, and coding a robot. Throughout our first competition season, it became increasingly apparent that practicing creativity outside of engineering had greatly influenced our mindsets when it came to developing strategies for the competition. For example, our members with a background in art were able to present their own ideas and collaborate with the rest of the team to design outside-of-the-box solutions for the intake and outtake systems. Our creativity-driven thought processes have always allowed us to come up with inventive design solutions. Ultimately, our team's performance, collaboration-oriented problem solving process, and our vibrant devotion to FIRST during its founding season was able to motivate and inspire other young women in our community to begin involving themselves in engineering through FIRST.

Our team is now composed of **18 students from 9th through 12th grade** with a vast range of interests and hobbies, such as dance, music, traditional art, and the humanities. These interdisciplinary backgrounds have continued to allow each of us to bring forth our own unique experiences to advance our engineering process. Because we don't require new members to have any robotics experience, we teach ourselves the skills that we need to excel at programming, engineering, computer-aided design, and research. Through giving all of our members, regardless of expertise, a chance to tackle the engineering-focused obstacles presented in the FTC competition season, our team both acknowledges and celebrates the intersectionality between the creative arts, humanities, and STEM. The responsibility of teaching ourselves new skills and sharing knowledge with other members has demonstrated the importance of fostering strong communities in order to motivate young women to enter STEM environments without fear of judgment or feelings of inadequacy. We strive to provide encouragement and empowerment in a field that is not always welcoming. Notably, our team's mission, which is to motivate female students to pursue engineering and computer science, allowed us to collaborate with Women in STEM, host discussions with alumni working in STEM, and assist our school's younger students' robotics team. We especially want to encourage the younger members of our school because as an all-girls robotics team, we have experienced firsthand the difficulties in pursuing STEM as women because it is a male-dominated realm. Thus, **the principal goal of our team is to make STEM more accessible for all women.**

Team Plan

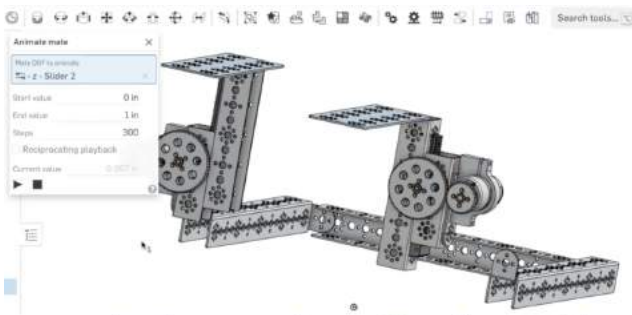
Our Team's Mission: Create A Sustainable Team, Teach Ourselves New Robotics-Related Skills Each Season, & Motivate Young Women To Pursue STEM.

Sustainability

In 2018, our team's four founding members' primary concern was developing a sustainable team due to a widespread lack of exposure to opportunities in both STEM and robotics within our school's larger community. As a result, we continue to devise new recruitment strategies, such as hosting interest meetings that are open to all Upper School students and presenting our team's work to the Computer Science I and

II classes at Spence. Additionally, we actively recruit 8th graders by inviting them to attend our meetings during our school's annual Upper School Visiting Day and reaching out to our middle school's FIRST Lego League team. We also specify roles among our team three years in advance and have new captains work closely with old ones in order to preserve knowledge among ourselves and establish strong, capable leadership. Our team's passion for both FIRST and STEM brings in new members and empowers women to pursue their interests in STEM.

Acquiring and Developing Skills



A snapshot from one of our self-made CAD video tutorials that shows how to implement a rack and pinion mechanism using Onshape

We are focused on teaching our members' foundational skills in engineering, programming, and design. In particular, we like to emphasize that new members do not need any prior robotics or STEM experience, which has encouraged students with a large variety of interests to join the team. Since many of our newer members have very limited experience in robotics, we have created guidelines, reference sources, and video tutorials to teach ourselves the skills we need in coding, computer-aided design, engineering, academic writing, and researching.

Hardware Classes

Template you should follow: HardwarePushbot

1. Change file name and match class & constructor name to said name
2. Declare your OpMode Members
   - "public DcMotor leftDrive = null;"
   - public [CLASS NAME] [name] = null;
3. Initialize OpMode Members
   - "leftDrive = hwMap.get(DcMotor.class, "left_drive");"
   - [name] = hwMap.get([CLASS NAME].class, "[NAME ON PHONE]");
4. Set Modes/Powers/Positions etc. (depends on what you are coding, I'm using a DcMotor class here as an example)
   - "leftDrive.setPower(0);"
   - [name].setPower(0);
   - "leftDrive.setMode(DcMotor.RunMode.RUN_WITHOUT_ENCODER);"
   - [name].setMode([CLASS NAME].RunMode.RUN_WITHOUT_ENCODER);
5. Delete what you don't need and adjust the comments

An example of code from our Java guides for new members

As many members were unfamiliar with Java programming, we dedicated time during our after school meetings to teach ourselves Java. We used tutorials we created last year to learn Java's syntax and the structure of hardware, teleop, and autonomous classes. We also assigned ourselves light homework to practice coding in Java and supplemented these assignments with weekly quizzes to refresh syntax fluency.

Outreach

Our active engagement with our school's larger community has been centered around providing insight into careers in STEM, highlighting female engineers, and promoting existing organizations that grant young women the opportunity to explore their interests in engineering.

Once a week, we spend time mentoring and working with the middle school FIRST Lego League robotics team. Our team helps them improve their programming and building skills, teaches them problem-solving strategies, and encourages them to explore their interests in STEM. One instance was assisting them in a mission where their robot had to flip a switch while the ending position of the robot differed each time.

Assisting the MS FLL robotics team

Additionally, we hosted a discussion with Charlotte Edelson, Spence '09. Edelson shared her experiences working for Viam Inc. as a woman in STEM to both students and faculty *(pictured below)*. We work with admissions to advertise our robotics team to all prospective students, and organize presentations to teach our school about our team's commitment to FTC.

In addition to encouraging young women in our own community to pursue STEM, we reached out to an organization called *Women in STEM* to help educate and empower more women of various locations and ages, but predominantly middle schoolers, who want to pursue STEM but don't know where to start or fear being pushed out of majority male STEM spaces. We also wanted to promote FIRST and its mission to other communities that serve to represent women in STEM. In collaboration with WiSTEM, we are working to provide an easy and accessible way for

girls to learn the fundamentals of engineering, programming, and robotics as well as how to get involved with FIRST. To accomplish this, we are continuously producing recorded lessons and a multitude of infographics (*example pictured on the left)* for WiSTEM's social media to give an introduction to FTC, FLL, building, and coding to educate the next generation of female roboticists. We are also working with WiSTEM to choose a speaker from their organization to discuss their experience as a woman in STEM and offer advice to the young female engineers and programmers in the audience.

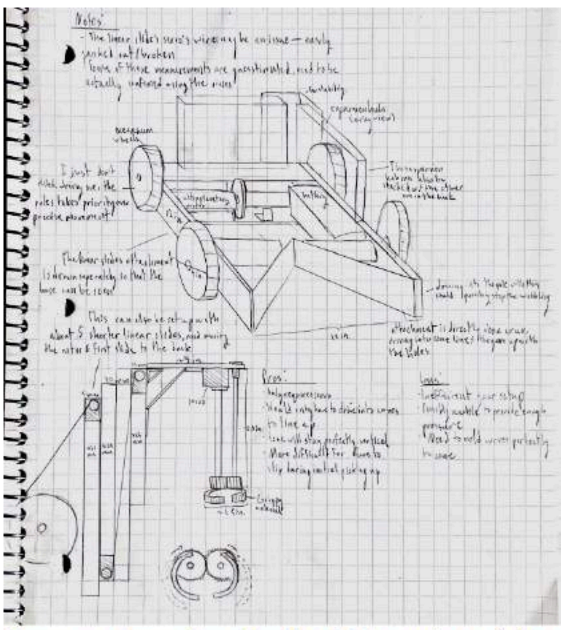
Additionally, this season, we have been accessing resources from beyond our school in order to further embed our team within FIRST's larger community of women engineers. We have reached out to the FIRST community for assistance in gaining a mentor, and have formed relationships by meeting with both Dalton Robotics and SARS. Because Spence lacks a reliable 3D-printer, we were able to coordinate with members of Team 9372, Standard Model, to print our U-shaped funnel and two beacons at Dalton. We have also received guidance from Danah Screen, who is a FIRST alumna and has been coaching FTC for the last 9 years. Currently, Ms. Screen is the Director of Robotics and K-12 Engineering Chair at the Dalton School. We receive advice from Dalton and use their full gamefield to scrimmage with Dalton teams, finalize our autonomous code, and practice driving.

Through our collective outreach efforts, we have learned to market our team and share our knowledge with younger students. We strive to continue educating young women inside and outside our school about FIRST, programming, engineering, and robotics by offering our support and creating accessible educational resources for anyone to use.

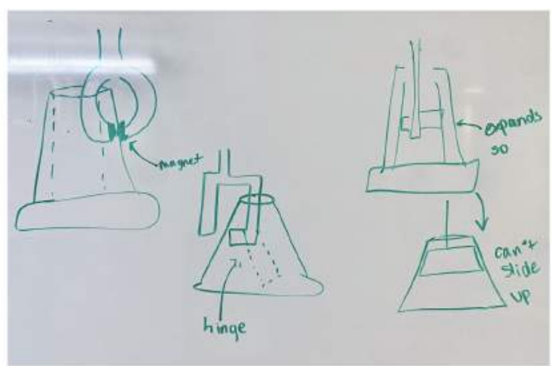
Designing, Building, & Coding the Robot

Brainstorming & Design Process

We host meetings daily from 3:30 p.m. to 8:00 p.m., and semiweekly for 30-minutes to build, program, troubleshoot, and set goals based on our progress. All of our members share the responsibility of writing in the Engineering Notebook, which allows every member to develop their skills in detailed note-taking as part of the engineering process. We start each season by tasking members with independently designing each aspect of the robot that we need to build, this season, prioritizing a **sturdy and space-efficient chassis** and a **combined intake and outtake system**. Then, we each presented our ideas in a show-and-tell style meeting and decided to integrate several of our conflicting intake proposals into one sketch. (For more details on the design process of our intake, please visit the *Building & Designing the Intake/Outtake.*) It is crucial that by the end of our design process, we have an efficient, reliable, and structurally sound design.

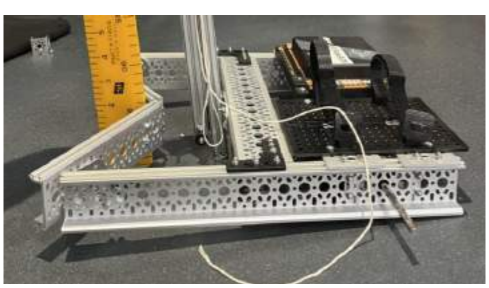


Peer-reviewed and edited blueprint of the robot that both inspired and guided our current design



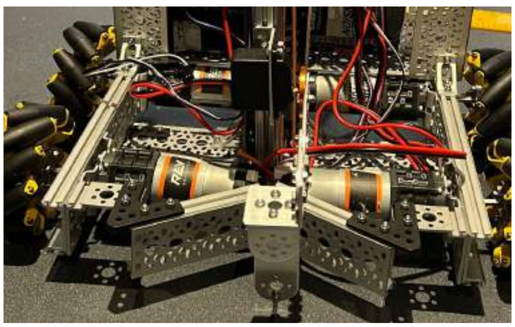
Multiple sketches of potential claws drawn by members at the beginning of the season.

Building & Designing the Chassis

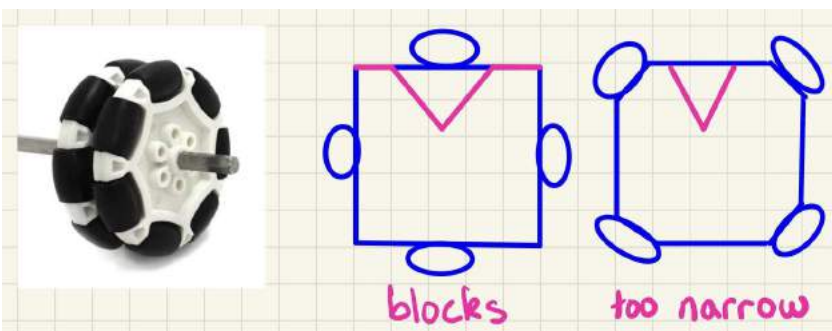


This season's game field requires robots to navigate through a complex maze of junctions and efficiently pick up cones. To ensure our robot could conquer these tasks, we deployed a light and compact design, gear ratios, holonomic drive, and built the front of the chassis inwards to resemble a "V" then later "U" shape. While the maximum dimensions for the robot are 18 inches x 18 inches, we aimed for the frame of our robot to be just 13.5 inches x 12 inches to allow the robot to drive through two adjacent junctions. Additionally, using C channels and flats for the chassis instead of heavier, larger U channels allowed us to lighten and quicken our robot, resulting in more efficiency when transporting cones.

To further amplify driving speed, we decided to optimize each motor's gear ratio. Dedicated gear ratio research revealed to us that a low gear ratio would allow for a greater max speed while a high gear ratio would be better for carrying heavy weights.

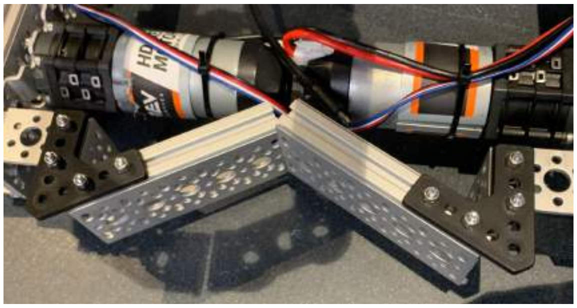


We specifically chose to increase our arm motor's gear ratio to 60:1 while decreasing our drive motor's gear ratio to 20:1 in order to increase torque while also increasing speed. After finalizing the ratios of each motor, we then attached them to the chassis parallel to the sides and facing inwards (*pictured on the left*).



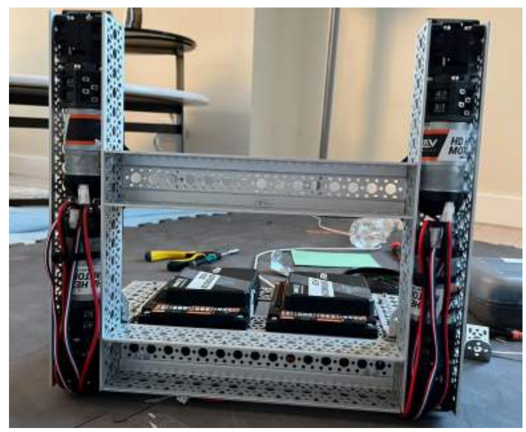
After outlining potential pathways from an alliance substation to various junctions, we concluded that a holonomic drive would be most beneficial as we often found it more efficient for the robot to drive side-to-side rather than around a junction. Next, we considered using omni wheels as the mecanum wheels we had at the time were an older, heavier model that would frequently fall off their respective motors. However, sturdier wheels would make up for our already lightweight robot, and implementing omni wheels would interfere with the design of the robot's frame because the inward front prevents any attachment *(pictured above)*. Ultimately, we decided to invest in newer mecanum wheels (*pictured above*), because they were the most compatible with our design and needs.

Our drivers found that accurately aligning the claw with the cone was difficult and time-consuming. So, using two C channels, we built a V shape *(pictured on the left)* in the front of the robot that funnels cones directly under the intake system as the robot drives into it, consequently saving us valuable time that would have otherwise been wasted on precisely orienting the robot.

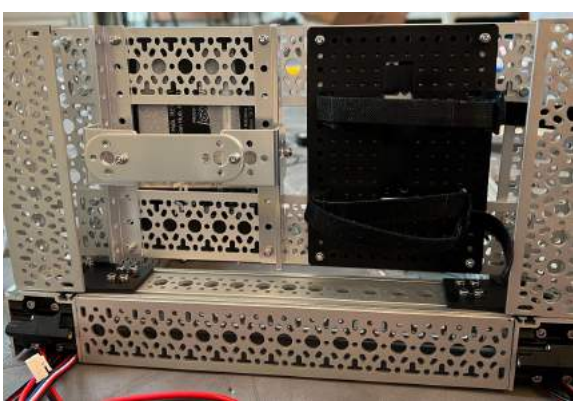


Chassis Improvements after Building & Driving

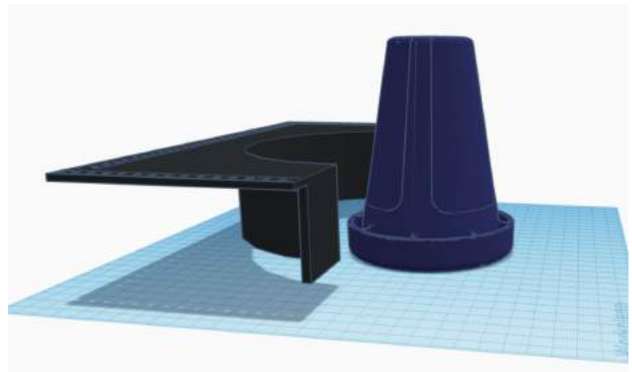
After driving the robot during the last qualifier, we found that our chassis was unable to support and evenly distribute the robot's weight, causing the robot to drive ~45° towards the left. We decided to rebuild our chassis to be more robust and compact. We decided to use the heavier U channels as opposed to C channels because the extra weight helped stabilize the robot (*pictured on the right*). Moreover, this allowed us to place the motors inside the U channels on the sides of the foundation to distribute motor weight evenly and make the center of the robot less crowded.

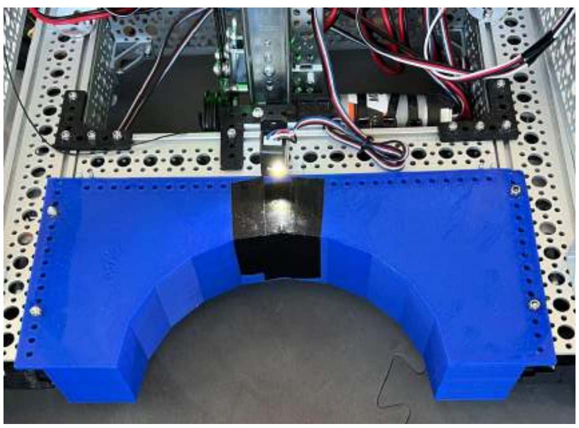


We reorganized the back plate so the phone and battery would face outwards while the expansion hubs would face inwards *(pictured on the left)*. This gave us easy access to the phone and battery while keeping the wires within the robot. To further manage the wires, we built walls on both sides of the robot using flats. These walls also provide a place to write our team number as well as attach our alliance markers and warning signs. We purposely placed the battery diagonally across the motor controlling our lift system to further even out the robot's weight.



Finally, we significantly improved our funnel system. Previously, we built the front of our robot inwards to resemble a V. In practice, however, it took too long for the cone to enter the V because the entrance of the mechanism was too narrow. Additionally, the cone's round shape was not compatible with the sharper, angular V, so it was often misdirected into unwanted positions. We decided to design a new, custom mechanism in CAD (*pictured right & below*) and 3D print it out with the help of Standard Model (Team 9372). Removing the four driving motors from the center of the robot created space

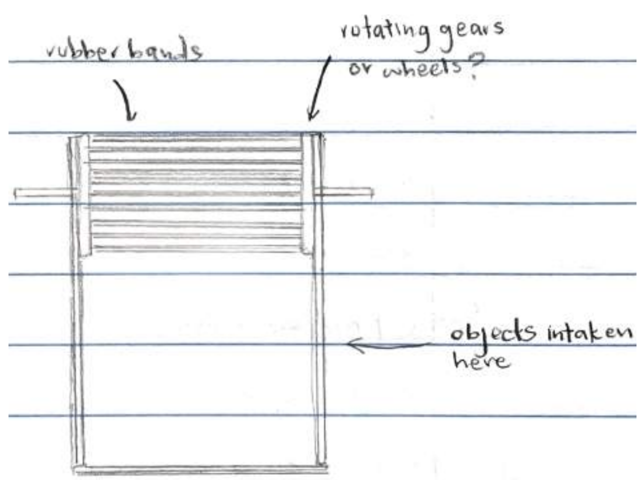




for the piece, which is also hollow to avoid using unnecessary filament and adding weight. Considering the lip of the cone, we made the piece low to the ground enough to prevent the cone from getting stuck under it. The curved shape also allows the driver to approach the cone at any angle and still funnel the cone directly under the claw. The U was designed flat on each side, with a radius slightly less than the diameter of the bottom of the cone, allowing our drivers to consistently line up the cone in the same place by driving towards the plexiglass behind the substation.

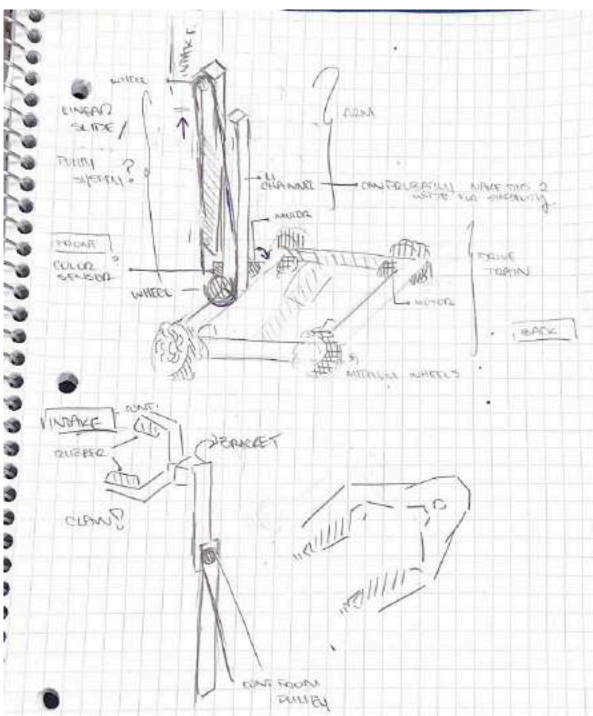
Building & Designing the Intake/Outtake

We began our design process by debating whether or not to use a joint or separate intake and outtake system system. An example of one of our separate system designs was to have a "spintake" to pick up the cones and an elevator to deliver them to each junction. The "spintake" would compose of a motor connected to two wheels where rubber bands are spanned across them with some tension *(pictured on the right)*. As suggested by the name, this mechanism would spin inwards to pick up the cone by having the

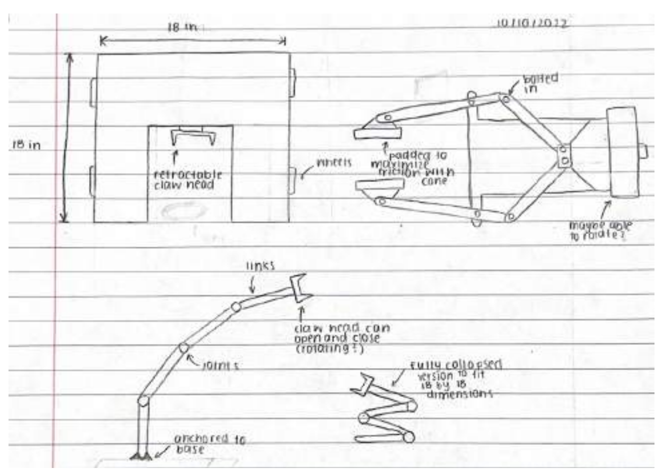


bands conform to the conical shape. The issue we ran into, though, is that there would be no way to guarantee the orientation of the cone before it arrived at the elevator platform. Not only was this design unreliable, but, as we realized with most of our separate intake and outtake ideas, both the transportation time and weight of the robot would suffer. Therefore, we officially decided on designing a joint system, meaning that the contraption would pick up and deliver the cone under one mechanism instead of two separate ones.

Next, we outlined the objective and needs of our intake/outtake system. In order to both pick up and drop cones onto each junction, the mechanism needed to be lightweight, easy to drive, able to deliver cones at different heights, and have a strong grip. Keeping this in mind, team members were tasked with independently brainstorming different designs before collaborating with the rest of the team to choose one. When it came time to present, almost each member decided on either an arm made of linear slides, extrusion channels, or a scissor lift to adjust to the junctions' heights. We decided on using extrusion channels to make our lift system because they were the lightest and simplest. We wanted to ensure our arm wasn't unnecessarily heavy and prioritize balance, since the lift would have to extend upwards.

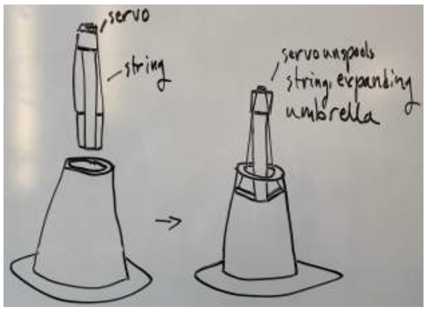


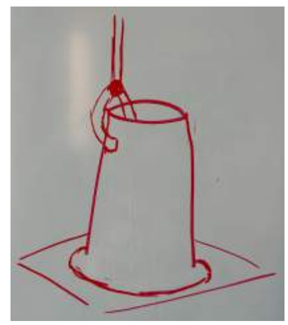
Our claw design, however, took significantly more time to design since we found ourselves debating between a claw that gripped the cone from the outside versus the inside. Three of our claw ideas, all which grab the cone from the outside, can be seen above and on the right. The first was made out of straight brackets and had a rubber-padded interior to both conform to the shape of the cone and apply friction for a

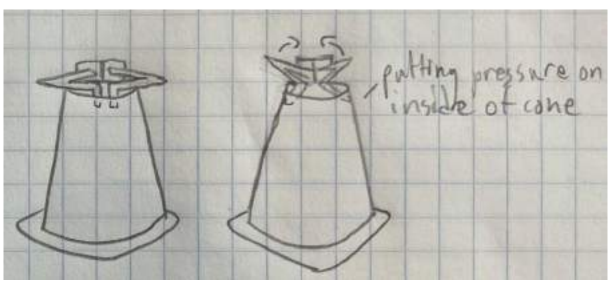


stronger grip. The second claw is similar to the first, while the third would be 3D printed to conform to the sides of the cone more accurately. However, our team was still concerned that an outwards claw would not exert enough pressure onto the cone, causing it to fall.

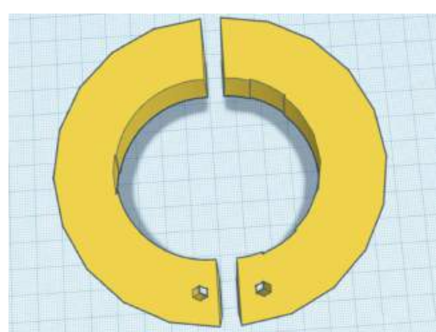
Our other claw designs involved picking up the cone from the inside. For example, **we were inspired by how an umbrella opens** to design a mechanism made of thin pieces that would be lowered into the top of the cone and then expanded *(pictured on the left)*. The expanded section would catch on the lip of the cone as the attachment lifted, carrying the cone with it. A limitation of this design, though, is that the inner lip on the cone is not solid, so the pieces could get stuck to the inside when trying to drop the cone onto a junction. Another idea was to create a "mini-claw", that rather than solely grabbing the outside of the cone, it would lower into the cone and grasp its side *(pictured on the right)*. However, we found the narrow opening at the top of the cone too small for a design like this to work consistently. Our final and most stable idea was to create an "inverted-claw" where we would insert brackets into the cone and turn them outwards to apply pressure from the inside *(pictured on the left)*. The main advantage of this design is that it would be extremely difficult for the cone to fall while being lifted. However, the main disadvantage of picking up a cone from the inside is that the top of the cone is a small target to consistently aim for and would require extreme precision from the driver, which is why **we built our chassis inwards** (as mentioned earlier) **to funnel the cone into the same spot repeatedly.**







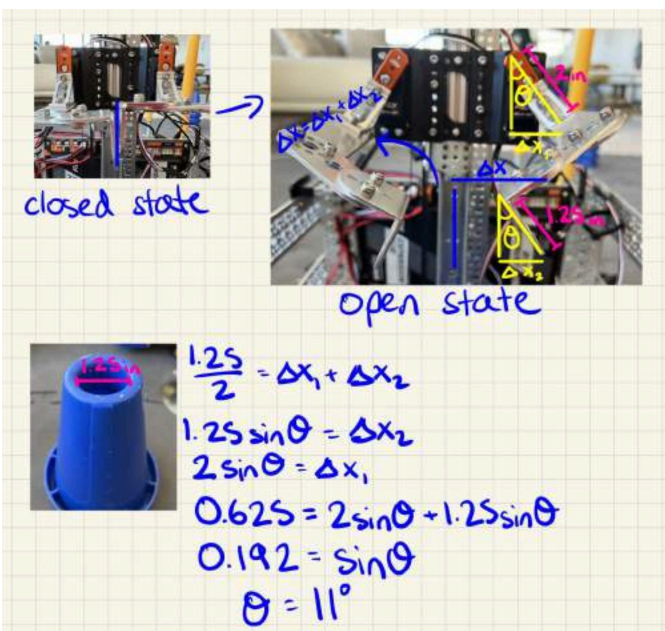
In the end, we decided to design two attachments: a custom-made claw to conform to the cone's shape to grasp it from the outside, and the "inverted claw" to pick up the cone from the inside. We wanted to create both to see which one



performed better and have a backup plan in case one didn't work.

We built our first claw in Tinkercad *(pictured above)* and matched its slope to that of the cone. Importing the cone into Tinkercad allowed us to cut out its exact shape to form the inside of the claw. After printing the claw, we lined the inside with rubber tubing to increase the friction between the claw and cone. We designed a gear system that kept one side of the claw stationed while the other would open and close to grasp the cone.

For our second design, we found that only one type of 90° bracket *(pictured on the right)* would fit inside the narrow opening of the cone. We calculated exactly how many degrees were needed to turn the claw outwards to pick up the cone. The distance between the starting position of both sides of the claw and their ending positions needed to be at least the diameter of the opening at the top of the cone in order to pick it up. Fortunately, we knew the brackets we had would work as our calculations *(pictured on the left)* proved that we needed to turn the claw outwards by at least 11°, which was achievable. So, we attached the two 90° brackets to servo motors, which would turn them inwards and outwards to pick up and drop the cone, respectively. Originally, we used one servo attached to a gear system to control the brackets, however, we found that using two servos worked better with our current inventory of parts.



Intake/Outtake Improvements after Building & Driving

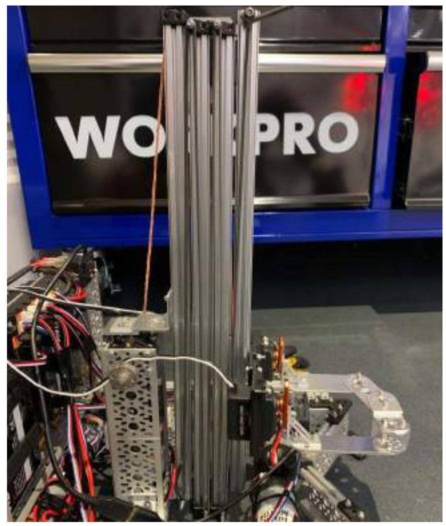
The biggest alteration we made to our robot was finalizing the mechanism used to intake/outtake cones. We were unable to 3D print our custom claw (*pictured on the right*) without defects

as we do not have access to newer printer models at our school. The printer struggled with smaller details, so it couldn't create holes for a hex shaft to fit through. Moreover, the slope of the printed claws did not match their digital models or the cone walls.

As 3D printing was a tedious process, we decided to use our "inverted-claw"

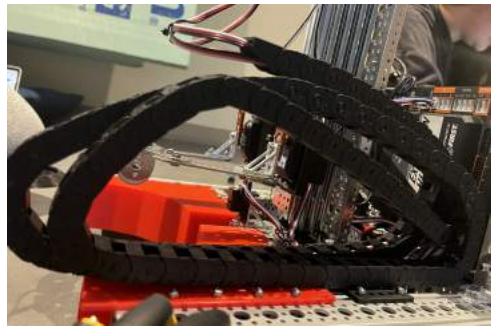
claw design *(pictured on the left)*. Initially, we had difficulty implementing this mechanism as we tried using gears and a single servo, which overcomplicated our idea and required parts we didn't have. Instead, we added a second servo, lightening and simplifying the overall design to optimize efficiency and speed when placing a cone. The force applied to the cone's interior made it virtually impossible for the cone to slip out, which made the mechanism consistently reliable no matter the condition.

As we began rebuilding, we had to make some modifications to our design to



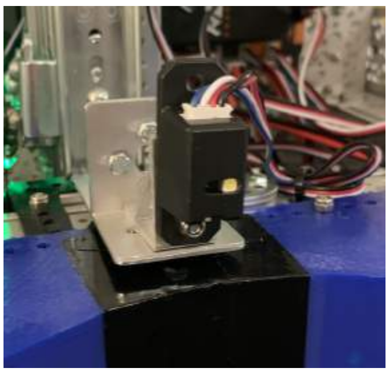
adapt to the challenges we faced. During testing, we realized three extrusion channels were not tall enough to lift the cone above the highest junction and therefore added another extrusion channel *(pictured left)*. We replaced the 10 inch C channels with 12 inch C channels in the chassi in order to allow room for a fourth extrusion channel. We also noticed a lot of strain and cracks on the end caps attached to the channels, which jeopardized the structural integrity of our lift system. Using the FTC reddit, we discovered that switching from a continuous lift to a cascading one would lessen the strain on each channel and instead distribute it more evenly across the four channels. This switch not only made the system sturdier and eliminated endcap breakage, but

also significantly increased the speed and smoothness of the lift. However, after more practice driving the robot, we decided to entirely replace the imbalanced extrusion lift with stabler linear slides (*pictured left*). Although we originally chose to use extrusion channels over slides to keep our robot as light as possible, we realized our arm was too flimsy to use a repeated amount of times and therefore opted for the more robust linear slides.



Another issue we encountered was when the wires for our servo motor would get caught on various parts of the robot, as they had to extend to the highest junction. To contain the wires and prevent them from catching onto something, we encased them in a drag chain (*pictured right*) in addition to the walls we built on the sides. However, the chain was too heavy and would cause the slides to fall, so we instead ziptied loops for the wire to move through to direct them without adding weight.

Programming



We began the Autonomous programming process by developing pseudocode and discussing the different routes the robot could take. We implemented a color sensor *(pictured left)* to enable the robot to read our custom signal sleeve and then park in the corresponding Signal Zone. While testing our sensor, we realized that green read higher than the other color values, so we scaled up the green value in order to prevent the robot from parking incorrectly. For the Teleop period, since we focused on robot precision, accuracy, and efficiency, we consistently place eight cones on as many junctions as possible. We implemented a button in the gamepad that slows the motors in both the wheels and arm while pressed. This helped us navigate the gamefield and lift the arm system to score cones more precisely. on and place a cone immediately after. To optimize points and consistency, we used motor encoders to program four preset heights that lift the arm to the ground, low, medium, or tall junction heights *(pictured right)*. These preset heights improved the efficiency and accuracy of the robot during the Teleop period. We implemented two separate buttons that manually lift and lower the arm in case we need to make small adjustments to the arm's

```
// Use dpad to raise and lower arm to preset levels.
// Low.
if (gamepad2.dpad_left)  {
    robot.arm.setTargetPosition(5214);
    robot.arm.setMode(DcMotor.RunMode.RUN_TO_POSITION);
    robot.arm.setPower(1);
}
// Medium.
else if (gamepad2.dpad_up) {
    robot.arm.setTargetPosition(8565);
    robot.arm.setMode(DcMotor.RunMode.RUN_TO_POSITION);
    robot.arm.setPower(1);
}
// Tallest.
else if (gamepad2.dpad_right) {
    robot.arm.setTargetPosition(11722);
    robot.arm.setMode(DcMotor.RunMode.RUN_TO_POSITION);
    robot.arm.setPower(1);
}
// Ground.
else if (gamepad2.dpad_down) {
    robot.arm.setTargetPosition(1000);
    robot.arm.setMode(DcMotor.RunMode.RUN_TO_POSITION);
    robot.arm.setPower(-1);
}
```

height. Moreover, we used variables such as *spinPower1* and *spinPower2* to make it easier to update/change the robot's speed throughout the competition.

Conclusion

We are incredibly proud to have achieved so many of our goals this season. From mentoring our school's FLL team to connecting with WiSTEM, we have spread interest in FIRST and encouraged young women to pursue STEM both inside and outside our community. Our collaborative design process uses our ingenuity to overcome engineering challenges, resulting in innovative, outside the box, and reliable robot solutions such as our custom U-shaped funnel and inverted-claw mechanisms. This season, we successfully created an overall functional, compact robot that easily navigates through the field of junctions and efficiently completes the task of transporting cones. Our robot uses a plexiglass structure to give it an aesthetic and clean appearance and incorporates sensors and automation, fulfilling our goal of creating an intelligent robot.