**Cost Effective Robotic Arm**

**Grant Proposal**

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**Engineering Abstract**

Many small businesses employ workers who spend numerous hours performing repetitive, tedious tasks such as preparing food or painting pencils. Prolonged repetitive motion for extended period of time often results in workers developing joint pain in their back, knees, and wrists. A robotic arm could help workers by completing these repetitive and time-consuming tasks, also freeing up the workers to perform other work they need to do. However, robotic arms capable of completing such tasks are usually very expensive, sometimes costing up to $50,000 per arm (Universal). Smaller businesses cannot afford such expensive arms and must continue to employ humans to complete necessary but tedious tasks. The goal of this project is to create a cost-effective robotic arm that allows companies to achieve consistent and accurate work while allowing workers to complete other work instead of tedious, sometimes painful, tasks. Additionally, robotic arms offer more opportunities for businesses. For example, research has been conducted on robots that can be operated remotely, allowing easier-to-manage work environments (Wan et al., 2012). Not only will the robotic arm be efficient as it will enable workers to complete other tasks, but it can also keep workers safe. Other than the pain that can be caused by doing a repetitive task for an extended period of time, some jobs require workers to interact with dangerous objects, such as items of high temperature. The robotic arm will allow workers to safely interact with such materials while avoiding direct contact, creating more jobs that humans could not previously do due to safety concerns in both the work environment or working with certain materials. Additionally, a robotic arm once trained will not need to be trained again, unlike human workers. A robotic arm would not only increase business efficiency but also workplace safety as an error in process would not result in injury.

One such small business that relies on human workers is Edible Arrangements. Edible Arrangements is known for its chocolate dipped fruit, especially strawberries. During an interview with a local Edible Arrangement owner, it became very obvious that the consistency and speed of work were

often a bottleneck during busy holiday times. Workers needed to put in long hours dipping fruit in chocolate and then had to shift focus to complete other tasks. Prolonged hours of same, repetitive work often done while standing resulted in back, knee, and wrist pain. Additionally, if a worker called in sick or was late, it became very challenging to keep up with the orders. Also, the workers were paid $30/hour and if they left the company, it took much longer to find and train a replacement, adding to the business expenses. A small business owner cannot afford an expensive industrial grade robotic arm. A cost-effective robotic arm would be extremely useful to such a business owner as it will help increase efficiency while keeping costs low and also allow workers to complete other tasks. The major goals of the cost-effective robotic arm will be to consistently and accurately dip strawberries into chocolate at the same or higher efficiency as that of a human worker. Next phase of the arm could focus on other fruits that Edible Arrangement has.

The robotic arm will focus on a standardized task of making chocolate-covered strawberries. This task requires consistency when dipping, and accuracy when placing the strawberry in the correct location. Not only does this adequately test the major goals for the robotic arm, but this process also contains a pick-and-place method that is often used in various tasks. A prototype of the design will be made using LEGO Mindstorm EV3 pieces and LEGO technic pieces. The prototype arm will be able to test if the design and shape of the arm allows the robot to function adequately. The prototype can also test the accuracy of the gripper design, as there are many different models with each having their own advantages (Universal, 2021). The prototype will be build using LEGOS as they are easy to build and do not require any complicated equipment. Also, modifications can easily be made because of how LEGOS work, and pieces can simply snap in and out of place to be replaced with other pieces for testing. Parts that work can be kept, but another design can be made by recycling the pieces from designs that did not work. After a successful gripper and arm design are made, the hardware can be copied into the final version.

The final version of the robotic arm would be made using aluminum (due to its comparatively light weight and cheaper price), plastic (because it can be 3D printed into custom shapes), servo motors, and controlled by either Raspberry Pi or Arduino (which will control and power the motors). Since the design would have already been tested to complete the pick and place functionality, this stage would test the accuracy and consistency using playdough strawberries. The accuracy would be measured by how close the arm can place the strawberry into the designated spot. The consistency would be measured by the consistency of both the placing of the strawberry, as well as the ability of the arm to apply the same amount of chocolate on the standardized playdough strawberries. These values can also be measured and modeled later with more complex systems that allow further studies on implications and iterations by recording the arm movements (Wei et al., 2021). Modifications can then be made to fix any problems or inconsistencies found in the models. Additional extensions can be added to increase efficiency, such as a remotely controlled robotic arm. A remotely controlled arm can allow someone to start and stop the arm virtually helping increase efficiency, especially during extremely busy times.

The next steps will be implementing the robotic arm in an actual work environment to test and compare its accuracy, consistency, efficiency, and durability in the work environment alongside human workers. The robotic arm should be able to consistently pick the strawberry, accurately dip it, and be effective in doing so at a speed that is the same as or faster than the human worker. It also should be durable to repeatedly perform the same task for a long time without breaking. A robotic arm at work would also free the human strawberry ‘chocolate dippers’ to allow them to focus on other tasks. By the end of testing, I expect the final version to be less than $500, which is significantly cheaper than many available products. Additional extensions can be added to increase efficiency, such as a remote-control robotic arm. The movement of the robotic arm can be controlled through a computer connected to the internet. An accuracy test conducted shows that the results of the output of the servo motor compared to the input send through an internet connection is between 97% to 99% accurate, as shown in Table 1.

A remotely controlled arm can allow someone to control the arm virtually which can give more flexibility in the work environment. It is still important for the arm to be accurate as otherwise it would not be able to properly complete the task.

| Location. | Output accuracy (%) | | |
|---|---|---|---|
| | Minimum | Neutral | Maximum |
| Base | 98 | 97 | 97 |
| Shoulder | 98 | 98 | 98 |
| Elbow | 97 | 98 | 98 |
| Wrist | 98 | 98 | 99 |

Table 1: Accuracy of a remote-control robotic arm for different joints (Kadir W. et al., 2012).

**Cost-effective Robotic Arm**

**Section II: Specific Aims**

This proposal aims to design a cost-effective robotic arm that is accurate, consistent, and efficient so that it can effectively complete tasks that humans currently have to complete allowing workers to complete other tasks, boosting overall workplace efficiency.

The long-term goal is to create a robotic arm that costs less than $500 per am to produce and can be successfully implemented in the workplace environment. The robotic arm will increase workplace efficiency by increasing the rate of production, as well as freeing employees to complete other tasks that they could not complete due to working on repetitive, labor-intensive tasks for numerous hours each day. The work we propose here will result in a cost-effective arm that can complete tasks, but work on making it more affordable while not compromising the efficiency of the robotic arm.

**Specific Aim 1: Accuracy (of picking and placing)**

The robotic arm should be accurate so that it can complete the tasks properly. Accuracy of the arm will be determined by the ability of the arm to pick the strawberry up from a specific starting location, and place the strawberry in another specific ending location. I will measure the distance from the desired location to measure accuracy, and the average distance of the trial will be the measured variable determining the accuracy of the design.

**Specific Aim 2: Consistency (of dipping the chocolate)**

The robotic arm should be consistent in its ability to complete the task multiple times. Consistency of the robotic arm will be determined by the ability of the robotic arm to dip the strawberry into chocolate. To test for a standardized process, a playdough strawberry will be made to guarantee consistent strawberry sizes. The playdough strawberry will then be dipped into water (as the chocolate and melting equipment is unavailable at this time). The water will mark how deep the strawberry gets dipped, and thus how much chocolate would have been on the strawberry. The consistency will be measured by ensuring that the correct level of water is coating the strawberry. If the strawberry is not completely coated by water, it would mean that there is not enough chocolate covering the strawberry. Similarly, if the skewer gets coated by water, it would mean that there is too much chocolate.

**Specific Aim 3: Efficiency (the time it takes to complete one round of dipping)**

The robotic arm should be efficient and worth using in the workplace environment. Therefore, the time it takes to complete the process will be measured, and this will be compared against the time it takes for a human worker to complete the task.

The expected outcome of this work is that the arm can accurately pick the strawberry mounted on the skewer, consistently dip the strawberry to have the same amount of chocolate coating, place the chocolate covered strawberry onto a different tray, and efficiently complete the entire process without taking more than 30 seconds longer than a human. Humans can see and react to what is happening, but the arm follows the same pattern each time. If the strawberry does not need to be dipped for as long due to a smaller size, humans can complete the process quicker than the robotic arm which will complete the process for a set time.

## Section III: Project Goals and Methodology

### Relevance/Significance

This project is significant because it will allow many smaller companies and businesses to buy robotic arms that they could not otherwise afford. A cost-effective robotic arm can increase the efficiency of work in factories and small businesses, as well as supply a more reliable and consistent workforce to complete tedious, time-consuming tasks that prevent workers from completing other tasks that they have to do. Robotic arms can also increase workplace safety. Additionally, robotic arms are also used to minimize errors (Kuntz et al., 2023).

**Innovation**

This project is innovative because while many robotic arms exist, this one will be cost effective, costing much less than the current industrial grade designs. Despite the significant difference in cost, the robotic arm will not have a significant difference in results, and will still provide accurate and consistent results. The robotic arm will be a better choice compared to competitor models that can cost from $5,000 to $50,000 (UFACTORY, n.d.).

**Methodology**

A prototype of this design will be made out of LEGO Mindstorm and LEGO technic pieces, programmed with a LEGO Mindstorm EV3 brain. This design will test the functionality of the physical design and can be easily modified to test different designs. For this case, testing will check which design can grip the strawberry, complete the task of dipping it, and placing it in the correct position and orientation as shown in Figure 2. Once a final design has been shown to work consistently, this design will be transferred into a final model constructed out of aluminum, plastic, servo motors, and programmed with Arduino or Raspberry Pi. These pieces were chosen for both their ability to properly complete the task and their cost effectiveness. Heavier material is not required for the robotic arm as it will not need to lift heavy things as most industrial grade robotic arms are designed to do. The final design will be tested for accuracy and consistency. For accuracy, I will measure the end position of the strawberry from the expected end position of the strawberry and minimize the variation as much as possible. For consistency, I will measure the weight of the chocolate on the strawberry so the dipping process is consistent. To do this, I will take a molded 'strawberry' made of playdough (to standardize the size and weight) and subtract from the final weight the weight of the strawberry prior to being dipped. Similar to the accuracy test, iterations will be made to minimize the variation in this test. Because the design was already tested in the LEGO version, only the code will need to be modified in the final version.

**Specific Aim #1: Determine the accuracy of the robotic arm.**

The objective is to create an accurate robotic arm that can place the strawberry in the correct location. Our approach (methodology) is to test the ability of the arm to place the strawberry in the correct position and then measure the distance. Our rationale for this approach is that the arm has to accurately pick and place items, and measuring which prototype has the least inconsistency in the values.

**Justification and Feasibility.**

The accuracy of the robotic arm is an important part because if the robotic arm cannot accurately place the end product in the correct position, it can throw off the entire assembly line. Without an accurate robot, the task will not be completed, and the robotic arm will not be usable. The robotic arm should be accurate, as shown in Figure 1, so that it can put items in the correct location. Accuracy is also important to ensure safety, especially if the use of the arm is extended to assembly lines.

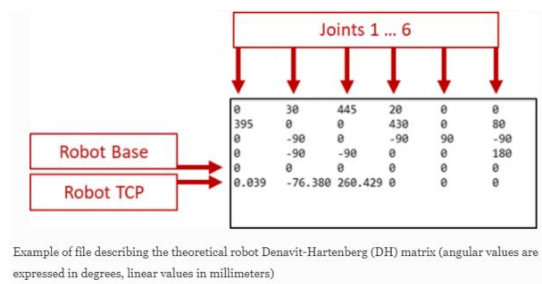


Figure 1: The values of a robotic arm's position using a laser sensor for accuracy (Lattanzi et al. 2020)

**Summary of Preliminary Data.**

In order to place the skewer in the correct location, tests had to be cunducted to ensure that the arm could place the skewer into a specific place. Different shapes of grippers were used, and recorded on a 0-3 scale to rank how close they could place the skewer to the correct location. The tests found that the angled gripper (Table 2) placed the skewer most accurately.

5. Angled Gripper

| Trial | Scoring |
|---|---|
| 1 | 2 |
| 2 | 3 |
| 3 | 2 |
| 4 | 3 |
| 5 | 3 |
| 6 | 3 |
| 7 | 2 |
| 8 | 3 |
| 9 | 3 |
| 10 | 2 |

Table 2: Accuracy tests for the gripper. This was the most accurate gripper ranked on a scale from 0-3, 0 meaning the gripper failed to pick up the skewer and 3 meaning that the gripper successfully placed the skewer in the correct locations

**Expected Outcomes.**

The overall outcome of this aim is to have a robotic arm that can accurately place the skewer, as shown in Figure 2, in the correct hole in the tray. This knowledge will be used to determine the accuracy, and the measured distance from the hole will tell how accurate or inaccurate the arm is at completing the pick and place process.

**Potential Pitfalls and Alternative Strategies.**

We expect there might be a problem where the robot cannot place a stick in the correct hole due to other strawberries getting in the way. To solve this, we can design a new tray where the holes are placed further apart, or where there is only one circular row of holes that is on a rotating platform so the robotic arm always places the strawberry in the same location and the platform moves instead of the robot.

**Specific Aim #2: Determine the consistency of the robotic arm.**

The objective is to create a consistent robotic arm to dip the strawberry in the same amount of chocolate each time. Our approach (methodology) is to test the ability of the arm to dip a playdough (standardized mass) strawberry and then measure the amount of chocolate on the strawberry. Our rationale for this approach is that the success of the final product relies on aesthetics and reproducibility. If a robot cannot apply the same amount of chocolate, the designs are incomplete. Inconsistent results in other cases can result in products acting in different ways, and some might not work at all.

**Justification and Feasibility.**

To test the consistency of the gripper, different gripper materials were tested. Testing included finding out which material increased the grip the most. The less the piece moves around while being held, the more consistent the end result is.

**Summary of Preliminary Data.**

The tests found that foam was the best, and could consistently hold on the skewer despite jerky movements. This was due to both the softness and friction provided by the foam. This allowed it to mimic how a finger grabs the skewer, and gave the best results for firmly holding the skewer.

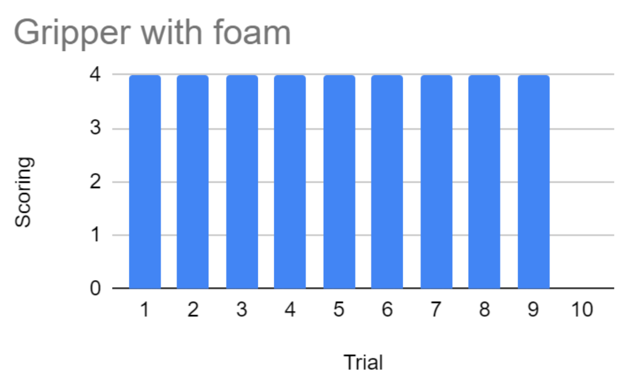


Table 3: Consistency_tests for the gripper. Foam was the most consistent material when ranked on a 0-4 scale. 0 represented that the gripper could not hold on to the skewer for 1 turn, and 4 represented that the gripper could hold on to the skewer for 3 jerky turns

**Expected Outcomes.**

The overall outcome of this aim is to create an arm that can get the same amount of chocolate on each strawberry, with a margin of error. This was tested by seeing if the gripper could hold onto the skewer consistently. This knowledge will be used for determining consistency and if the arm can complete a repetitive task.

**Potential Pitfalls and Alternative Strategies.**

We expect that there could be more inaccuracy when the strawberries are of different sizes. Since I am standardizing strawberry size, this will not be a problem when testing, but as part of the extensions, a camera can be used to see the size of the strawberry to determine how long it should be dipped.

**Specific Aim #3: Determine the efficiency of the robotic arm.**

The objective is to create an efficient robotic arm that can complete the process of dipping the strawberry without taking too much time. Our approach (methodology) is to compare the time it takes for a human to dip and then the robot. The goal is that the robot takes no more than 30 seconds longer than the human. Our rationale for this approach is that if the arm operates too slowly, then it will not be worth having in the workplace despite being more accurate. If the arm cannot keep up with the rate of production, then it will cause the business more loss than help.

**Justification and Feasibility.**

To ensure that the robotic arm will not affect the production rate of chocolate covered strawberries, the arm should be efficient. To meet this requirement, the time it takes for the robotic arm to complete one round of dipping strawberries will be compared to a human worker. The robotic arm should take no more than 30 seconds longer than the human worker to complete this task, otherwise the arm will be less efficient.

**Expected Outcomes.**

The overall outcome of this aim is to ensure that the robotic arm is efficient so that it will not lower the production rate of chocolate covered strawberries. This knowledge will be used for making sure that the arm can complete the task fast enough that it does not interfere with the rest of the work that needs to be done, such as packing the strawberries.

**Potential Pitfalls and Alternative Strategies.**

We expect that the arm could take longer than the desired speed, thus negatively affecting the production. To fix this, the motors can be made to move faster, or sensors can be added to reduce the time spent dipping the strawberries by detecting when the strawberry is covered rather than using a timer.

## Section III: Resources/Equipment

For this project, there are three parts: prototype, final, and extensions.

The prototype stage relies on LEGO Mindstorm and LEGO technic pieces due to their ease in modifying for iterations for testing. They can be programmed with LEGO Mindstorm EV3 software, which is not the most accurate, but easy to modify which is good for testing the different prototypes and seeing which ones can properly achieve the task.

The final stage requires aluminum, plastic, and servo motors. These materials were chosen for their characteristics. Aluminum is durable, comparatively cheap, and lighter when compared against other metals commonly used in robotics. However, it also requires expensive machines to shop into the correct shape and size. Therefore, plastic will be 3D printed and used to create complicated designs, such as those needed for the grippers. Additionally, rubber, cloth, or other materials might be used to increase the grip of the design. Servo motors were decided to be the most fitting motor for an arm of this style, as other motors would likely be overly powerful and therefore not be needed. The control system needed for this is either Raspberry Pi or Arduino (software used being Python or Arduino IDE, respectively), as these are commonly used to control mechanical pieces such as motors. Wires and zip ties (to keep the wires out of the way of motors and other mechanical pieces that could damage the wires) would also be used. In order to power the motors without risk of damaging the Arduino, a power converter is needed. A power converter also allows for control over how much voltage each motor gets at any time, providing more control over the system. Additionally, the Arduino system in consideration does require an external device – such as a computer –to power and control the Arduino.

The extensions are other sensors and similar pieces that can be added on. For example, a laser distance sensor can be used to see moving piece or non-standardized variables. For instance, since the chocolate is stored in a container, as it is slowly used up, the level of the chocolate slowly decreases. The robot can be hard programmed to dip slightly lower each time; however, the design and the code would be more accurate and consistent if there was a sensor measuring the location where the arm needs to go (Lattanzi et al., 2012). Additionally, the sensors can lead to the robot being more efficient as rather than the motors aligning themselves to the correct location, distance sensors can detect the location of the arm, and where the sides of the container are. Sensors can also increase the accuracy in any case as shown in Figure 3, but will lead to more complexity as the arm will no longer repeat the same action due to the sensor. Another possible extension includes modeling the robotic arm to allow for a more accurate representation and testing of the design in simulations, leading to more efficient methods of testing and designing iterations (Iqbal et al., 2012). A final extension that is possible is to make the robotic arm remotely operated. A remotely operated robotic arm can have multiple benefits, such as someone does not need to constantly keep watch over the robotic arm. Instead, it can be remotely controlled and if something goes wrong, remotely stopped. The tasks can also be completed more efficiently by completely cutting out the need for any human monitoring, therefore causing the process to be more cost effective (Rahman et al., 2019). These extensions are not part of the final model because they might cost more to implement and therefore go above the $500 goal of production per robotic arm.

## Section V: Ethical Considerations

Ethical considerations for this project include safety. Potential risks include any danger to humans, such as if someone's hand or clothing gets caught in the machine. The control panel (only part that the human will need to operate with) will be isolated from the rest of the robot so that no close contact is needed. Also, it will always be easily accessible so the robot can be quickly turned off in an emergency. The programming of the robot can also make it so that no human interaction is needed while the robot is running allowing anyone working with the robot to maintain a safe distance from gears and other moving pieces. With this design, no one will have to operate with any piece of the robot that can cause damage at any time. The hope is that this will cause no reason for someone to engage with the robot at any time that might be dangerous to humans. If some pieces or mechanisms could prove to be dangerous, there has been research about how to minimize injury due to robot interactions (Bicchi et al., 2004).

## Section VI: Timeline

The goal for this project is to finish prototyping and start the final project by the end of December break. The final project will be completed by February, and extensions will be added in after.

**Section VII: Appendix**

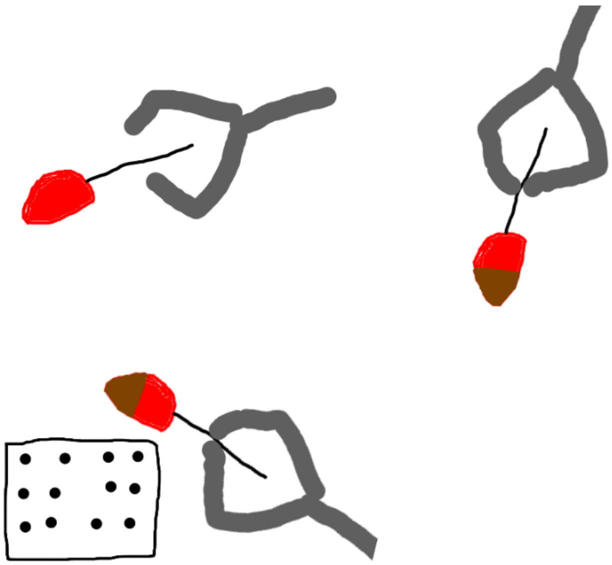

**Figure 2:** Process of the strawberry being grabbed, dipped, and placed into the tray by the robotic arm

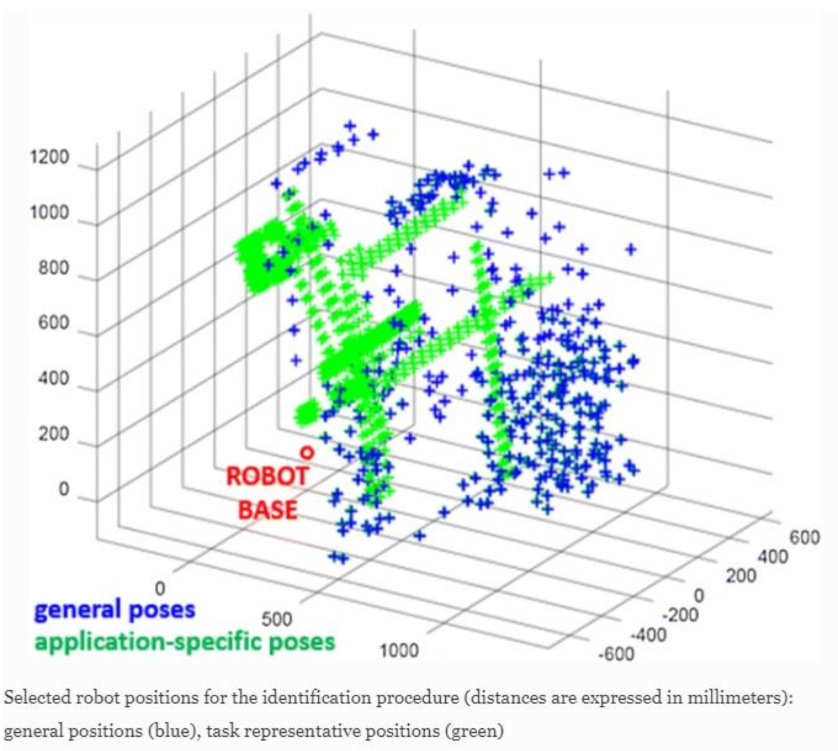


**Figure 3:** Accuracy of a 6-axis robotic arm with and without the laser sensor (Lattanzi et al., 2020).

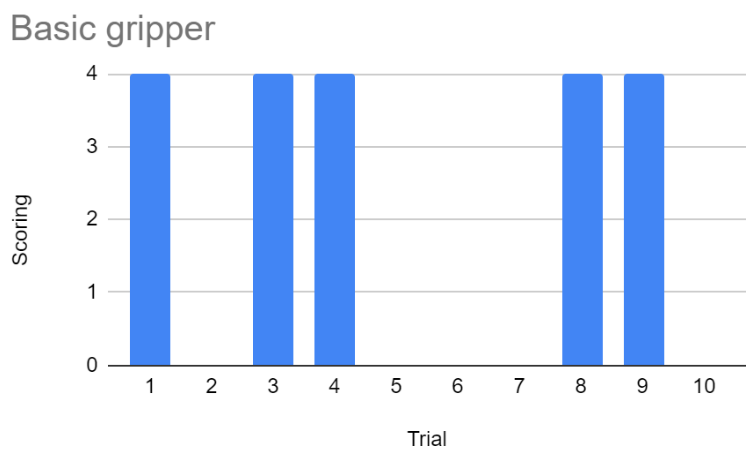


**Figure 4:** Gripper made of small LEGO pieces. The pieces could not hold the skewer often.

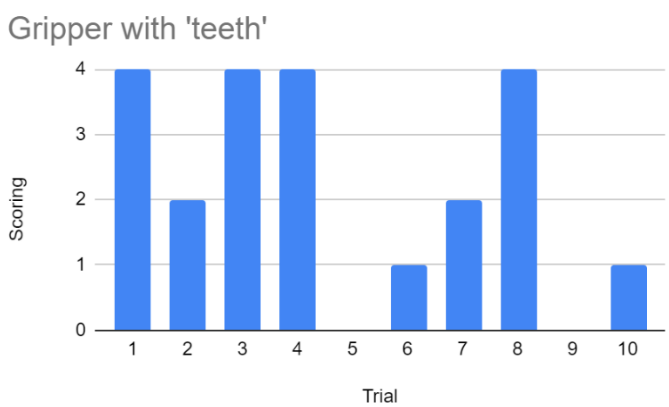


**Figure 5:** Basic gripper with the addition of LEGO H-connectors. This allowed it to grab better, but there was not enough friction to hold the skewer.

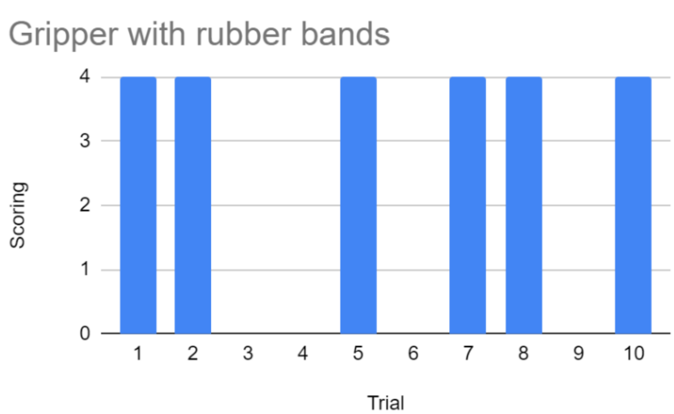


**Figure 6:** Toothed gripper with the addition of rubber bands for friction. The rubber bands' shape caused some issues with grabbing the skewer, but it held better than without rubber bands.

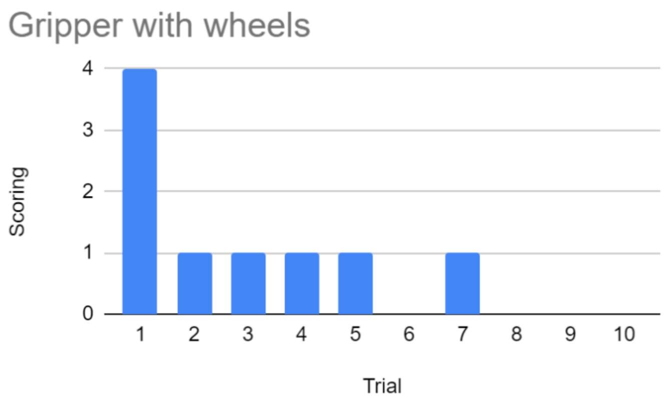


**Figure 7:** Replacing the H-connectors and rubber bands with LEGO wheels. The size and weight of the wheels prevented the arm from functioning properly

1. Basic Gripper

| Trial | Scoring |
|---|---|
| 1 | 3 |
| 2 | 2 |
| 3 | 2 |
| 4 | 3 |
| 5 | 2 |
| 6 | 2 |
| 7 | 2 |
| 8 | 2 |
| 9 | 2 |
| 10 | 2 |

**Table 3:** The accuracy test for the standard LEGO gripper

2. Gear straight gripper

| Trial | Scoring |
|---|---|
| 1 | 0 |
| 2 | 0 |
| 3 | 0 |
| 4 | 0 |
| 5 | 0 |
| 6 | 0 |
| 7 | 0 |
| 8 | 0 |
| 9 | 0 |
| 10 | 0 |

**Table 4:** Accuracy test for a 3D printed gripper. There was an issue that prevented the gripper from closing and holding the skewer.

| 3. Scissor straight gripper | |
|---|---|
| Trial | Scoring |
| 1 | 2 |
| 2 | 1 |
| 3 | 3 |
| 4 | 3 |
| 5 | 2 |
| 6 | 1 |
| 7 | 1 |
| 8 | 3 |
| 9 | 3 |
| 10 | 3 |

**Table 5:** Accuracy test for 3D printed gripper. The sizes and ratios caused inconsistency.

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