Leap into Learning: A Biomechanics Tool for Interactive Education in Jumping Mechanics

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Abstract

Biomechanical concepts are present in many everyday activities, but exposure usually occurs in high school or college. The goal of the project was to develop an interactive model to educate children about biomechanics. To show the power and force produced while jumping, a platform was created consisting of air pumps, load cells, and LED strips connected to an Arduino Uno for computations using MATLAB. Visual aids included a ball that rose from the air produced when landing. A vertical rung stand provided jump height measurements interactively. After testing, the device met the established criteria, however improvements could be made.

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Chapter 1: Introduction

Biomechanics is encountered in many aspects of everyday activities and shows how the body interacts with the environment through physics concepts. The concepts of biomechanics are relatively easy to understand but most people do not get introduced to them until high school or college. There are not many educational products on the market that show biomechanics concepts to young children. Earlier exposure to these concepts can spark curiosity and inspire the next generation of biomechanists to enhance the field. One method of mass exposure to new ideas is through community outreach events that offer a safe learning environment for people of all ages to experiment and learn. The purpose of this project was to create a device for outreach events to teach elementary and middle-school kids about biomechanics concepts through a hands-on activity.

To successfully create a device to teach kids about biomechanics, it needed to be primarily fun, interactive, and safe for all kids to use. From there, biomechanics concepts were incorporated into the device so that the children using it would gain exposure to biomechanics. Given that the device would be used by many children, it also had to be built robustly to withstand all types of uses from all demographics. With these goals in mind, the team began brainstorming different ideas for the device. After thoughtful consideration, the team decided to create a jump platform that generated air to lift a ball in a tube for a visual display of the power produced. The vertical rung stand provided another interactive method to measure jump height. The pumping mechanism was inspired by one of the exhibits at the Boston Children's Museum where children sat on seats to generate air for a ball to travel up the tube to demonstrate power. The rung attachment was inspired by a Vertec™ vertical jump tester modified for smaller children and was affordable to assemble. The platform used load cells that mathematically calculated jump height and other useful values similar to an AMTI force plate or a Just Jump mat that can be found on the market for a very expensive price.

With the design in mind, the team worked on fabrication and coding to bring the idea to life. Cost-effective materials like aluminum, polycarbonate, and plastic were all used to assemble the design. A user-friendly button interface was created for ease of use and allowed the MATLAB code to progress seamlessly with accurate results. A visually appealing display was generated to show the output measurements of jump height, flight time, force produced, power, and takeoff velocity. LED lights were incorporated into the code to signal to the user when the code is calibrating and when the device is ready for jumping.

After fully fabricating the device, the team tested it on the intended audience to determine whether the device met the initial objectives first described. The first testing was performed in a controlled environment on a 6-year-old who was in first grade at the time. The addition of foot markers on the platform and interchangeable balls were the primary changes that resulted from that initial testing. Then, a community outreach event was held at Vernon Hill Elementary School for mass testing with the device. Approximately thirty 6th graders tested the device. The team split the device into two sections, the vertical rungs and the jump platform. This helped reduce wait time and made it easier to collect data. The students enjoyed the repeatability of the device and many tried to improve their jumps after their first try. Some students were interested in the biomechanics aspects of the device, which meant that the device was successful in sparking curiosity in young children. Overall, the students had a great time interacting with our device while learning something about jumping and the device was still functional after mass testing.

The team wanted to make this device self-automated but could not properly code it due to time and knowledge constraints. The device should be made automated in the future so that the need for someone to use the code on a computer is eliminated. Other recommendations would be to improve the portability of the device and to use stronger materials so that the device can withstand more uses. Recommendations regarding the durability of the air pumps included using springs for additional support. The durability of the air pumps and their connection to the jump platform could also be improved for stability and less risk of shifting due to shear force. For ease in setting up the model, the adjustability of the rungs can be improved by enhancing the sliding mechanism.

Chapter 2: Literature Review

The purpose of this literature review is to provide background knowledge on biomechanics and the concepts that are to be taught. It also dives deeper into how children are engaged through different methods of learning. The chapter concludes with the current models on the market that teach young kids about biomechanics.

2.1: Biomechanics Concepts

Biomechanics can be defined as the application of classical mechanics to biological or medical problems [1]. It combines principles from physics, biology, and engineering to study the mechanical aspects of living organisms. Mechanical influences on biological systems can range from the smallest particles, like nucleic acids and cells, all the way to organs and the human body system [2]. At the tissue and organ levels, there are many aspects of mechanics that can be applied to physiology including bones, muscles, soft tissues, cartilage, and the spine. Biomechanists primarily want to understand the forces, stress, and strain on the body to prevent future injuries, give treatment to existing injuries, analyze patterns, and locate joint force trends [1].

When it comes to applications, biomechanics can be useful across different domains. Biomechanics plays a vital role in designing orthopedic implants and prosthetics. It also serves as a useful tool for optimizing and improving human performance in sports through interactions with the player, equipment, and environment. When recovering from an injury or surgery, biomechanics aids in the development of rehabilitation protocol and tailors treatment plans based on physiological assessments. Out in the industry, human ergonomics and biomechanics go hand-in-hand in providing optimal working postures and workplaces to allow for comfort and safety. For robotic devices aimed towards restoring human movement, biomechanics is needed to safely design and assist those with mobility impairment. With so many applications affecting human health and life, the interdisciplinary nature of biomechanics drives innovation and improves our understanding of how organisms are mechanically impacted.

The concepts listed below were all the ones the group came up with when brainstorming ideas. All of these concepts explain how mechanics impacts the human body. Figure 1 shows the concept map of how all these concepts are connected.

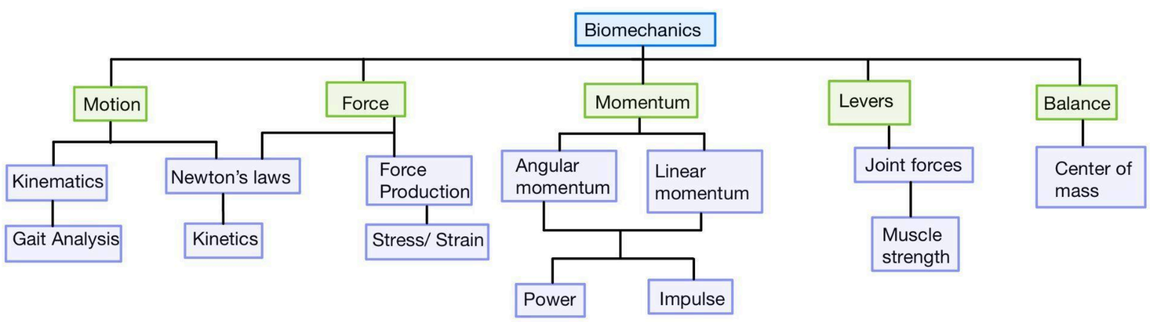


Figure 1. Concept Map showing connections between biomechanical concepts

2.1.1: Stress & Strain

Stress is the measure of how forces are distributed along a material and how the material behaves to it. The formula for stress is the applied force divided by the cross-sectional area of the surface affected ($\boldsymbol{\sigma} = \frac{F}{A}$) with the units in Pascals (Pa) [4]. Stress can occur depending on the way the force is applied like compression, tension, or torsion. Strain is the resulting deformation of an object when stress is applied and can be calculated as the change in length over the original length ($\varepsilon = \frac{L-L_o}{L_o}$) [4]. Biomechanists use stress and strain to identify where the concentration of loads is placed and determine if they are the cause of load injuries. For calculating complex problems and visually representing those results, biomechanists use Finite Element Analysis (FEA). FEA is a method of solving differential equations that often uses a simulation software to find the mechanics of materials like stress and strain [3]. A stress-strain curve is another visual representation of the mechanical properties of a material such as the one in Figure 2. From a curve, one can get Young's modulus, elastic region, plastic region, and ultimate tensile strength, and determine if a material is ductile or brittle [4]. Stress and strain are useful in identifying stress fractures on a bone. If a person loads a bone too much from running, a hairline stress fracture can develop which could grow into a visible fracture and cause tremendous pain. Understanding stress and strain is crucial in biomechanics because it helps researchers assess how tissues and structures within the human body respond to external loads and forces. By quantifying stress, biomechanists can evaluate the safety, stability, and performance of biological tissues, implants, and prosthetics.

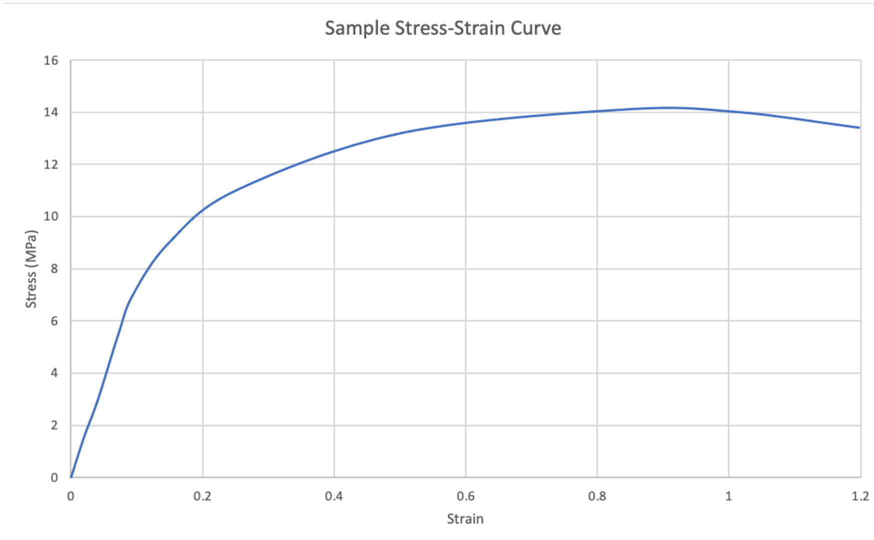


Figure 2. Stress-strain curve for a sample material

2.1.2: Power

Power is defined as the amount of work over the length of time it's completed. It's a rate of energy transfer through the body using the nervous and muscular systems. The full equation is $P = \frac{Fs}{t-t_o}$ where F is the amount of force, s is the displacement, t is the elapsed time, and t_o is the original time. The unit for power is a Watt (W) or Joule per second (J/s). Sports biomechanists use power as a gauge to see what the maximum force an athlete can produce within a short time for a sport. Examples of power being demonstrated include Olympic lifting, sprinting, and jumping.

2.1.3: Joint Forces & Levers

Forces are loads that can be represented as an object acting on another object. Forces can be external, such as an outside object acting on the human body, or internal, where forces within the body help with stability. A joint is where two bones are connected through cartilage and ligaments. When an external force is applied to the human body, the joints have muscles to stabilize the bone from breaking. In Figure 3, the biceps and triceps muscles work as a pair where the biceps contract and the triceps extend creating a lever system to hold a basketball similar to the one with a book [5]. To solve for the forces, a free-body diagram and coordinate system must be drawn to analyze which forces are going in the same and opposite directions. From there, statics equations can be used and sum all of the forces in the x and y directions and moments equal zero. Joints are also classified as levers. A lever system is the coordination of the bones and muscles to create human movement. Its functions are to generate a muscular effort to overcome loads and increase the speed of a given movement.

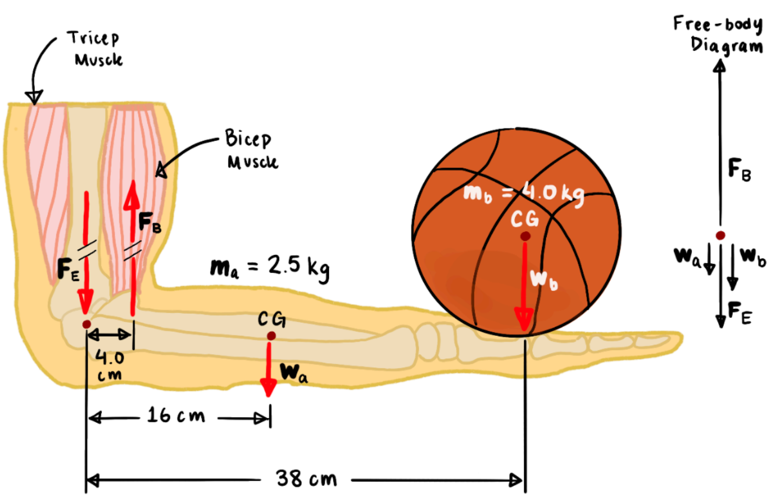


Figure 3. A free-body diagram of a person holding a basketball

2.1.4: Muscle Strength

Muscle strength is defined as the maximal force a muscle or muscle group can produce at a specific velocity [6]. Muscles are determined by the amount of muscle fibers located in a muscle. Muscle fibers and tissue grow when it breaks and regenerates after using it intensively. The soreness after overusing a muscle is called delayed onset muscle soreness (DOMS). Muscles, however, are not the only system to determine muscle strength. The nervous system also helps by driving the muscles to perform the action with maximum effort. When the muscles have been torn or partially injured, examiners can assess muscle weakness using a strength scale from 0-5. At 0, there is no muscle activation. As the scale increases, the examiner would look at whether the full range of motion is achieved and if the muscles can be activated against gravity and resistance [7].

2.1.5: Center of Mass

The Center of Mass (COM) is the point at which a body's entire mass is concentrated. Similarly, the Center of Gravity (COG) is the point where the weight of the body is evenly distributed and can be represented as the gravitational pull on the body. In most cases, the COM and COG are at the same point on the body. To calculate the COM, the weighted average of the positions of each body segment is needed while taking mass and coordinates into consideration. If the body is unevenly distributed from the COM, then the body would fall as a result. Depending on how your body is positioned, the COM changes with respect to your body parts. COM can be beneficial in sports like gymnastics, high jump, and pole vault because they allow for the body to jump higher than normal and keep balance on a skinny platform.

2.1.6: Momentum and Impulse

Momentum is the quantity of motion of an object dependent on its mass and velocity. The formula for momentum is $p = m\Delta v$ where p is momentum, m is mass, and v is velocity. Momentum obeys the law of conservation which means that in a closed system, total momentum is constant if no external forces act on it. Linear and angular momentum are the two types of momentum. Linear momentum deals with motion in a straight line while angular momentum is about rotational motion. The force that causes a change in momentum is called the impulse. It can be calculated as the integral of the force-time graph or $J = F\Delta t$. When using the impulse-momentum theorem, the equation of $F\Delta t = m\Delta v$ can be used to find the missing variable in a problem like impulse, applied force, or change in velocity.

2.1.7: Gait Analysis

Gait analysis is the measurement of someone's movement including standing, walking, or running [8]. Measurements can be acquired using joint kinematics, foot pressures, kinetics, and electromyography. Through clinical tests, gait analysis can be used for diagnosing a disease, assessing the severity of an injury, monitoring progress, and predicting the outcome following intervention [8]. These clinical objectives can correlate to practical applications including rehabilitation, improving sports performance, and footwear assessment. In gait analysis, there are two phases in a normal forward step: stance and swing phase. The stance phase is when one leg is on the ground absorbing all forces and contact from the body. The swing phase is the other leg coming forward and preparing the body to absorb forces.

2.1.8: Force Production

Force production is the action of producing force from the body onto an external surface or area. It can be simply measured using Newton's Second Law which states Force =

mass*acceleration. Force production can happen when running, jumping, punching, or any movement where muscles are involved in extending and contracting. When punching something, a person can gather another force from the ground and transfer it through their body and output out of a leg or arm. The kinetic chain allows for punches and kicks to be powerful because it is all one seamless transfer of energy from the ground through the arms. Power and force production go hand-in-hand in providing measurements for measuring human performance.

2.2: Learning Approaches for Children

In youth education, it is important to incorporate learning techniques that are engaging and dynamic. Not only is it about obtaining knowledge but it is ensuring that that knowledge is retained and applied practically. Below, is the literature review that goes over approaches that are claimed to be effective in educating young learners.

2.2.1: Active Learning through Hands-on Learning

One way to educate young learners is by implementing hands-on learning. This method encourages participation and practical engagement with concepts creating an immersive experience [9]. Interacting with models, conducting experiments, and using other tools develop young learners' curiosity and critical-thinking skills. Moreover, when learning takes place in group settings, it promotes interaction and encourages knowledge sharing and the exchange of ideas. Collaborative learning allows children to explore how the subject matter relates to their lives, fueling their curiosity.

2.2.2: Utilizing Visuals and Interactive Approaches

The integration of interactive strategies is fundamental in education for young learners. Research supports the idea that visual aids improve comprehension and retention of concepts [9]. Visuals such as diagrams, videos, and interactive displays create an environment that facilitates understanding while establishing connections to theoretical knowledge. The textbook "Educational Psychology: Developing Learners" by Jeanne Ormrod provides details on children's learning and emphasizes that the use of visual aids as effective educational tools enhances comprehension of concepts among children. While the textbook focuses on children, its principles can be applied to adults as well [19]. Furthermore, interactive learning experiences like simulations, virtual laboratories, and educational games enhance engagement levels by encouraging participation from students. Providing representations of the subjects being taught also encourages involvement from learners.

2.2.3: Gamification and Engaging Learning

The integration of game design and engaging learning techniques has become a tool in education. Gamification is the use of game elements and principles in a non-game context to engage and motivate more people in activities [20]. This can be seen in Kahoot, which is a popular online game-based learning platform [10], and Duolingo, a language-learning app that uses gamified lessons to teach vocabulary, grammar, and conversation skills [21]. By incorporating elements inspired by game design, such as challenges, rewards, and healthy competition educators harness the motivation and natural curiosity that young learners possess.

This approach transforms the learning experience into something enjoyable where students actively seek knowledge and engage with the content in their own way.

2.2.4: Inclusive and Customized Instruction

Recognizing and accommodating learning styles and abilities is important in youth education. Inclusive and customized instruction emphasizes content and strategies to align with each student's strengths and needs. This approach ensures that every learner regardless of their background or learning profile has opportunities to achieve their full potential [11]. Providing a variety of materials and collaborative learning opportunities creates a learning environment that embraces diversity while promoting fairness.

Effective youth education relies on utilizing a range of learning approaches. Utilizing hands-on learning, incorporating interactive strategies, implementing gamification techniques, and fostering inclusive instruction all contribute to creating an engaging educational experience. These methods not only help learners acquire knowledge but also enable them to apply it in their daily lives.

2.3: Assessing Learning from Exhibits

Scientific concepts are found in several areas of everyday life. Public places including museums, zoos, and aquariums make science readily available to the public and are sometimes referred to as “informal learning settings” [9]. These places promote what is called “free-choice learning.” “Free-choice learning” relies heavily on self-direction and self-selection. Since learning is heavily based on the visitor’s perception, it is hard to design an exhibit that achieves the same level of learning for everyone. Falk and Dierking believe that the meaning people create from a museum experience is based on the visitor's personal background and knowledge, the social interactions that occur during the visit, and the physical environment that the exhibit creates [11]. Additionally, educational content presented to children has to be memorable for it to affect children's learning. In a case study presented in the book "The Tipping Point" comparing both Sesame Street and Blue's Clues, it was shown that the presentation of the content will dictate whether a child is going to understand the information conveyed [22]. Measuring learning in these environments is often based on the observable behaviors of visitors. These behaviors often include "approaching an exhibit, reading signage, asking questions, discussing the exhibit, and duration of time spent at the exhibit" [9]. Engagement is believed to be the most important aspect of an exhibit. Engagement can be encouraged in different ways and often involves the senses, such as touch tanks in aquariums and audio tour options. Children especially need time to look at the unfamiliar environment before they can learn anything from one exhibit. Once the roaming period is over and they settle on exhibits, they seem to engage with exhibits in a "stop-start manner" and revisit the exhibits that interest them [11].

A framework for assessing learning experiences in science centers was created in 1998 by Barriault. Seven learning behaviors that occur when a visitor engages with an exhibit are grouped into three categories. Initiation behaviors are usually the first to occur and allow the visitor to engage with the exhibit with little risk [9]. These involve doing the activity or watching someone else do the activity. Transition behaviors occur when the visitor repeats the activity and has a positive response due to the engagement [9]. These behaviors indicate comfortability. The final category, breakthrough behaviors, occurs when visitors make meaningful connections. Breakthrough behaviors involve the visitor referring to a past experience, sharing information with other people, and becoming engaged and involved with the exhibit [9]. When a visitor expresses these behaviors, they are taking full advantage of the exhibit's intended learning opportunity [9]. This framework is used by museums to assess the impact of their exhibits because most of these behaviors will occur during a meaningful experience, although they may occur in different orders.

2.3.1: Biomechanics Models on the Market

Currently, on the market, some devices can calculate multiple biomechanics concepts using different methods. One of those methods is through jumping. Two devices on the market, the Just Jump System and the Vertec vertical jump tester, each use separate techniques to teach similar concepts. The Just Jump System developed by Probotics Inc. is a flat rubber mat of 27" by 27" that calculates jump height from the flight time, or the time the person is in the air. Athletes primarily use this device to measure their vertical height but because of its simplicity, kids can also jump on it repeatedly to find out their jump height, making it a promising device. The only downside is that the mat costs $800 and the results do not compensate for the high price [23]. One study conducted a validation report to see if it accurately measures jump height compared to a force plate sampled at 600 Hz. The researchers found that the Just Jump System overestimates the jump height by 0.1m so a correction equation was created to adjust the height output [23]. Overall, the Just Jump System is a basic device that can compute jump height but its expensive price and lack of visuals may deter children from learning more about biomechanics.

Another device on the market is the Vertec vertical jump tester. This device does not have any computations associated with it and is instead a classical method of calculating jump height. Participants first measure themselves on the device with their hands extended to touch the bottom rung. From there, the number of rungs hit can correspond to the vertical height of the person. What makes this device intriguing is its simplicity and its repeatability for kids and athletes. The downsides of this device is also the price which is at $930 and it weighs 55 lbs making it hard to carry despite having wheels [24]. The small difference is that this device measures vertical height from the fingers rather than from the center of mass like the Just Jump system. Another study wanted to validate if jump height calculated from the Vertec vertical jump system was similar to an app on the phone that can visually calculate jump height. The study concluded that consistency between the two methods was acceptable but accuracy between each other was unsatisfactory [24]. With these two devices dominating the sports market, it's clear that the similarities in simplicity and repeatability are key aspects when designing a successful device.

Chapter 3: Project Strategy

This chapter provides the group's strategy for designing our model starting with the initial client statement. From there, the design requirements were outlined including objectives, constraints, and design standards. The revised client statement is the culmination of everything discussed in this section and is how the group defined the project.

3.1: Initial Client Statement

The project's extent derives from the initial project statement provided by Professor Karen Troy: Design a biomechanics demonstration for hands-on learning and outreach events

1. Show the anatomy of a joint
2. Allow the joint to flex and extend using a cord representing major muscle groups
3. Measure and display, in real-time, the forces within the joint
4. Manipulate the system by adding weight to the limb or changing the muscle moment arm
5. A physical setup that is intuitive to use and visually appealing for students of all ages
6. Participant goal: learn about anatomy and see that the forces inside joints are large compared to limb endpoint forces

3.2: Design Requirements

3.2.1: Primary Objectives

1. **Fun and engaging:** The model should be fun for elementary and school-aged children to use. The model should keep the users engaged so that they do not quickly become

disengaged with it.

2. **Visually attractive:** The model should display data in an attractive way. Different colored lights or sounds may be incorporated.
3. **Quick measurements:** The model's activity should occur quickly and provide measurements in under 30 seconds so that the children do not lose interest before the data is displayed.
4. **Educational:** The model should be able to be used as an educational tool to teach children a concept related to biomechanics. The device needs to be simple enough for a child to use and understand.
5. **Portable:** The model should be easy to move around and transport.
6. **Long-lasting**: The model should have easily assembled parts and withstand lots of uses.

After establishing the primary objectives, the team collectively created a Pairwise Comparison Chart shown in Table 1 that displays the objectives of the model and their respective rankings. Based on the rankings, the team applied these ranks and compared them to all learning concepts to determine which five concepts the group would use.

Table 1. Pairwise Comparison Chart of Primary Objectives

	Fun	Portable	Interactive	Visually attractive	Quick measurements	Provide knowledge	Feasible	Total
Fun	X	1	0	1	1	1	1	5
Portable	0	X	0	0	1	1	1	3
Interactive	1	1	X	1	0.5	1	1	5.5
Visually attractive	0	1	0	X	0	1	1	3
Quick measurements	0	0	0.5	1	X	1	1	3.5
Provide knowledge	0	0	0	0	0	X	0	0
Feasible	0	0	0	0	0	1	X	1

From the Pairwise Comparison Chart, the group listed out all the concepts and determined if each one met the objectives using a Pugh Analysis.

Table 2. Pugh Analysis for Biomechanics Concepts

	Rank	Force	Stress/Strain	Gait Analysis	Power	Joint Forces/Levers	Muscle Strength	Balance/COM	Momentum/Inertia
Fun	4	1	1	1	1	1	1	1	1
Portable	3	1	1	0	1	1	1	1	0
Interactive	4	0	1	1	1	1	1	1	1
Visually attractive	1.5	0	1	1	1	1	0	1	1
Quick measurements	2	1	1	1	1	0	0	1	1
Provide knowledge	0.5	0	1	1	1	1	1	1	1
Feasible	1	1	1	0	1	1	0	1	1
Total		**10**	**16**	**12**	**16**	**14**	**11.5**	**16**	**13**

The scores were totaled and the concepts that scored the highest were stress & strain, power, center of mass, joint forces, and momentum.

3.2.2: Secondary and Tertiary Objectives

Secondary and tertiary objectives were created to give more detail on each primary objective the team wanted in the design.

Table 3. Fun and Engaging Secondary Objectives Definitions

Fun and Engaging	
Secondary Objectives	Definition
Ability to Play with the Model	Kids must be able to play with the model through cooperation or competition.
Draw Curiosity	The model should catch kids' attention and draw their curiosity for an engaging experience.

Table 4. Interactive Secondary Objectives Definitions

Interactive

Secondary Objectives	Definition
Involving Senses	The model should incorporate human senses such as touch and sight to be interactive.
Active Participation	Through active participation as an individual or team, kids should be engaged partially or entirely throughout the demonstration.

Table 5. Visually Attractive Secondary Objectives Definitions

Visually Attractive	
Secondary Objectives	Definition
Size of Demonstration	The model should be big enough for everyone to see from at most 30 feet away. Results and any visual aspects should also be visible from the same distance.
Type of Visuals Used	When displaying information, the presentation should use eye-catching visuals and nice pictures to grab the kids' attention. Sounds, haptic feedback, and warm colors should also be considered to enhance the experience.

Table 6. Educational Secondary Objectives Definitions

Educational	
Secondary Objectives	Definition
Relevant Information	The model should introduce biomechanics concepts while relating it to real-world experiences that kids encounter.

Passive Learning	While a demonstration is occurring, kids should also be provided a smaller, related activity that enhances their learning experience.

Table 7. Quick Measurements Secondary Objectives Definitions

Quick Measurements	
Secondary Objectives	Definition
Response Time	The model should produce response times of less than 30 seconds to help retain students' attention.
Response Accuracy	The results from the model should be integers for students to understand easily.
Session Reset	Each demonstration's results should be independent of each other when comparing data. At the end of each demonstration, the model will reset.

Table 8. Portability Secondary Objectives Definitions

Portability	
Secondary Objectives	Definition
Easy to Move	The model should be able to be pushed, pulled, or carried easily.
Compactibility	The model should compact into a manageable 5' x 5' space for traveling.

Table 9. Long-Lasting Secondary Objectives Definitions

Long-Lasting	
Secondary Objectives	Definition
Replaceable	Any component that needs to be replaced frequently should be easily obtainable.
Durability	The model should be built out of flexible, but durable material so that it can withstand hundreds of uses and traveling.

Table 10. Fun and Engaging Tertiary Objective Definitions

Fun and Engaging	
Tertiary Objective	Definition
Comparison of Results	Kids should be able to compare their results and have a leaderboard to promote healthy competition.

Table 11. Interactive Tertiary Objectives Definition

Interactive	
Tertiary Objectives	Definition
Minimum of 2 Senses	The model should have a minimum of 2 senses to promote interactivity. The most practical ones are sight, sound, and touch.

Table 12. Educational Tertiary Objectives Definition

Educational	
Tertiary Objectives	Definition
Use of Metaphors	When presenting educational material, the use of metaphors can help kids understand better what the team is trying to teach them.

Table 13. Quick Measurements Tertiary Objectives Definition

Quick Measurements	
Tertiary Objectives	Definition
Simple Feedback Interpretation	The feedback from the model should be basic enough for kids to understand.

A Pairwise Comparison Chart as shown in Figure 4 was created by the team to rank each secondary objective. The rankings can be found in Figure 5 which helped influence what weight the team should assign each one for the Pugh Analysis.

Objectives	Ability to Play with the Model	Draw Curiosity	Involving Senses	Active Participation	Size of Demonstration	Type of Visuals Used	Relevant Information	Passive Learning	Response Time	Response Accuracy	Session Reset	Easy to Move	Compactability	Cost Efficient	Durability	Total
Ability to Play with the Model	X	1	0.5	0	1	1	0.5	0.5	1	1	1	1	0.5	1	0	10
Draw Curiosity	0	X	1	0	1	0.5	1	1	1	1	1	1	1	1	0.5	11
Involving Senses	0.5	0	X	0	1	0.5	1	0.5	1	1	1	0	0.5	1	0	8
Active Participation	1	1	1	X	1	1	1	1	1	1	1	1	1	1	0	13
Size of Demonstration	0	0	0	0	X	0	0.5	0	1	1	1	1	1	1	0	6.5
Type of Visuals Used	0	0.5	0.5	0	1	X	1	0.5	1	1	1	1	1	1	0	9.5
Relevant Information	0.5	0	0	0	0.5	0	X	0	1	1	1	1	1	1	0	7
Passive Learning	0.5	0	0.5	0	1	0.5	1	X	1	1	1	1	1	1	0	9.5
Response Time	0	0	0	0	0	0	0	0	X	1	1	1	1	1	0	5
Response Accuracy	0	0	0	0	0	0	0	0	0	X	0.5	0.5	0.5	0.5	0	2
Session Reset	0	0	0	0	0	0	0	0	0	0.5	X	1	1	1	0	3.5
Easy to Move	0	0	1	0	0	0	0	0	0	0.5	0	X	0.5	1	0	3
Compactability	0.5	0	0.5	0	0	0	0	0	0	0.5	0	0.5	X	1	0	3
Cost Efficient	0	0	0	0	0	0	0	0	0	0.5	0	0	0	X	0	0.5
Durability	1	0.5	1	1	1	1	1	1	1	1	1	1	1	1	X	13.5

Figure 4. Pairwise Comparison Chart of Secondary Objectives

RANKING	Objectives	
1	Durability	
2	Active Participation	
3	Draw Curiosity	
4	Ability to Play with the Model	
5	Type of Visuals Used	Passive Learning
6	Involving Senses	
7	Relevant Information	
8	Size of Demonstration	
9	Response Time	
10	Session Reset	
11	Response Accuracy	
12	Easy to Move	Compactability
13	Cost Efficient	

Figure 5. Ranking of Secondary Objectives

3.2.3: Constraints

1. **Time:** The project should be completed within the academic year (August-May).
2. **Cost:** The budget for this project was $250 per person, which resulted in a total of $1,250.
3. **Safety:** The device should operate safely without causing harm to the children engaging with it. Additionally, the device should be able to withstand constant use by children and multiple demonstrations without being damaged.
4. **Supervision:** Supervision would be necessary for the children to use the model in a safe manner.
5. **Portable:** The device should remain within a limited 5ft x 5 ft dimension to allow for transportation between different locations. The weight of the model should also be limited for ease of transportation.
6. **Data Output:** The timeframe for collection and output should be minimal so that the children are provided with real-time data and explanations.
7. **Bystander Engagement:** It is possible that the model will only allow for one person to use it at a time. The model should therefore allow for bystanders to be engaged even if they are not the ones directly engaging with the model.

3.3: Design Standards

The model developed by the team had to adhere to certain standards to maintain the welfare of the participants. Based on the requirements and objectives of the model established by the needs analysis, the standards that the team had to adhere to were:

1. **ISO/IEC 17025 - Testing and Calibration laboratories**

   Testing and calibration standards are crucial to demonstrate the quality of the process to provide valid results.

2. **ISO/IEC 27001 – Information Security Management**

   Information Security Management standards will assure the user that the data obtained by the model will not be misused and therefore avoid possible ethical concerns.

3.4: Revised Client Statement

Based on the objectives and standards, the initial client statement was revised as follows: The objective of this project is to create a model that can effectively educate elementary and middle school-aged children about biomechanics through supervised interactions within a 10 x 10ft space. This model will be designed to be fun, engaging, portable, durable, and safe, with the capability to provide accurate, real-time measurements in under 30 seconds. Additionally, it will have visually appealing data display features, facilitate concept presentation, and record interactions for analysis.

Chapter 4: Design Process

4.1: Needs Analysis

Based on our final client statement, the final design is intended for elementary and middle school-aged children. The design needs to be fun and interactive, portable, able to provide quick measurements, and educational. To meet these needs, there are specific functions that the device must be able to accomplish.

Existing educational tools for elementary and middle school children fall short of delivering an engaging learning experience when it comes to biomechanics. Our project seeks to bridge this gap by developing a model that offers real-time measurements, enables concept explanations, and encourages analysis through interaction. This approach aims to promote an understanding of the underlying principles of biomechanics.

4.1.1: Interactive Requirement

For the device to be interactive, it must be able to take in external information from the user before proceeding with an analysis. The device must then be able to take those individualized inputs and convert them into an output. This output must also be attractive for children to look at and engage with. The use of different colored lights or sounds may be incorporated into the design. Since children are the intended users, the device must be simple to operate, and the results must be easy to understand.

4.1.2: Time Requirement

Since this device is intended for children, the output must be given within a quick time frame. If the device takes too long to produce the visual outcome generated from its inputs, there is a risk that the child will disengage with the device before the outcome is displayed. A time frame of under 30 seconds was ultimately decided upon.

4.1.3: Portability Requirement

The final device produced is intended to be used during different educational events. Therefore, the final design should be able to be transported. This may involve being able to place wheels on the bottom of the device so it can be pushed to different locations or limiting the size of the design so it can be transported in a vehicle.

4.2: Learning Objectives

Since our design is meant to be used as an educational tool, learning objectives were also created for each biomechanical concept. These learning objectives will be used as a guide for evaluating the extent to which the final design can be used as an educational tool. The learning objectives for several biomechanical concepts are as follows.

4.2.1: Stress and Strain

The learning outcomes are for kids to understand what stress and strain are, their applications to the human body through everyday activities, and how a stress-strain graph can help identify information about the stress a material or body part is experiencing.

4.2.2: Power

The learning outcomes are for kids to gain an understanding of power, and its practical applications across various activities, and learn about what is involved in generating power through visual aids.

4.2.3: Center of Mass

The learning outcomes are for kids to understand the basics of center of mass (COM), how different factors affect a human body's COM, and how the body reacts to regain balance through visual aids and demonstrations.

4.2.4: Momentum

The learning outcomes are for kids to understand what momentum is, how to calculate it, how momentum can be conserved, and how it can be added with other momenta through visual aids and demonstrations.

4.2.5: Joint Forces

The learning outcomes are for children to learn about the components of a joint, how the forces in a joint are produced, what changes the amount of force produced, and be able to make a comparison to levers.

4.3: Conceptual Designs

The team developed possible ideas for the project that would fit under each of the five categories used for the learning objectives. Some of the ideas fit under multiple concepts and were placed in the “multiple concepts” category. The table below is the culmination of this brainstorming.

Table 14. Potential activities under each of the five biomechanical concepts

Stress/Strain	Center of Mass	Momentum	Joints	Power	Multiple Concepts
Using a strain gauge	Holding weight on one side of the body to observe the differences in center of mass	How softball involves momentum (hitting and pitching activities)	Skeleton model that includes: - Neck - Forearm - Jaw - Dislocations and double jointed joints - Degrees of freedom	Show the power produced by a punch	“Biomechanics Olympics”: - Jumping - Multiple sports
Model a bone breaking	Standing on one foot to observe differences	Competition to see how close participants can stop at a line without crossing it	Joints involved in kicking	Show the power produced from a track and field block start	Skeleton model: - Stress - Momentum - Joints
Model stress injuries	Different positions while standing to observe the effects on the center of mass	Model an arm injury	Joint forces due to holding weights	“Powerhouse” activity involving multiple activities that generate and use power	
Putting weights on different parts	Different positions while laying	Golf activity			

of the body	down				
Model to show pressure in the feet	Wearing a heavy backpack	Bowling activity			
Experiment with different style of shoes to show pressure differences	Martial arts	Using a water balloon to model momentum			
Model to show how casts help fractures		Spinning in a chair to model angular momentum			
		Model of head collision injuries			

Once there were multiple ideas under each concept, the primary objectives were used to determine which ones would be most feasible to do. The team used check marks if the idea could most likely be done, a ½ if the idea could potentially be done, and crossed off the ones the team thought would most likely not be possible. The ideas that received a check mark were modeling a bone breaking, the softball activity, and the skeleton model. The ideas that received a ½ were the strain gauge, model of stress injuries, holding a weight on one side of the body, and the arm injury idea, which could be combined with bone breaking.

4.4: Preliminary Designs

In the initial stages of the design process, four primary concepts were generated from the conceptual designs, taking into account both the client statements and objectives. This section will present these concepts and provide the pros and cons for each idea.

4.4.1: Bone Breaking

This concept would have modeled an Instron machine flexure test to show how a bone handles forces. A "guessing game" type activity would have been incorporated where children would guess the amount of force required to break the bone. This idea was fun and engaging, especially since it required children to guess a number and see the immediate effects of the amount of force applied. In addition to guessing, the model could also show children stress and strain on the bone through Finite Element Analysis. The biggest downfall to this idea was the materials that would need to be used. The material would have needed to be cheap and easy to obtain large quantities of. The cleanup of the broken pieces, as well as the set up for the new pieces, was the most difficult aspect of this design.

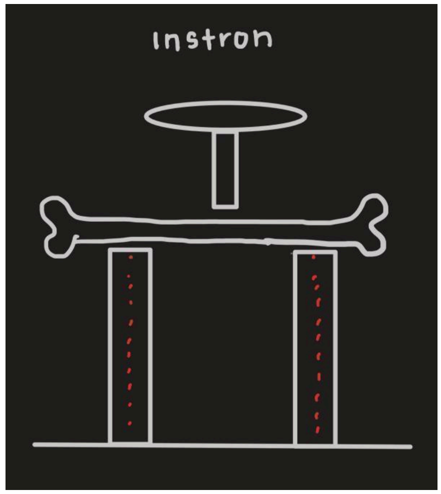


Figure 6. Sketch of Instron Demonstration for Guessing Game

4.4.2: Skeleton Model

This concept would be similar to the skeleton models on the market that children can interact with. The idea behind this concept was for kids to play with the bones individually each attached with strain gauges. Through this interaction, the children could also understand the maximum loads a human bone can withstand and the effects of excess force. The model would also be easily attached or detached for quick assembly. When children pushed or pulled on the skeleton, sensors would indicate if joints underwent forces and stress. The attaching and detaching of joints would provide a visual for how much force would occur in possible dislocations. The possibility of lost pieces was a high concern for this idea.

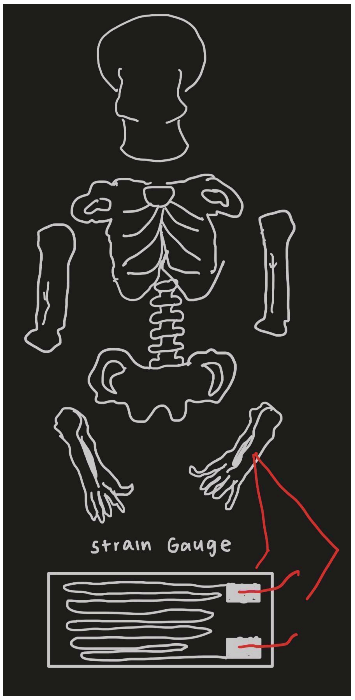


Figure 7. Potential Skeletal Model with Strain Gauge

4.4.3: Softball

Children would participate in hitting a softball within a portable batting cage. The idea behind this concept would teach kids about the biomechanics of hitting a ball from the moment they swing the bat to hitting it afterward. There was also the possibility of including a separate group learning about the biomechanics behind a softball pitch. Having two activities in one model would increase collaboration between the children and also increase overall interaction. There were many safety concerns with this activity as someone could hurt the pitcher or themselves. This activity would require constant monitoring to avoid possible safety hazards. Another concern was accessibility as this activity requires a fairly large amount of motor skills to complete the movements.

4.4.4: Jumping

In this concept, children would participate in jumping as high as they can on a platform that can calculate their jump height. The amount of force and the power that they produce from jumping would also be calculated. Additionally, stress and strain topics could also be introduced through the jumping activity through supporting visuals. The team anticipated the individualized results to be a design challenge since the force readings would need to be different for each child jumping. Such results would also need to be presented in a timely manner. Accessibility was another concern for a jumping activity as there are many motor skills required for jumping that individuals may struggle with.

4.5: Research at the Boston Children's Museum

To gain more insight about how to best create an educational model for children, the team decided to visit the Boston Children's Museum in Boston, Massachusetts. The team's goal was to observe how children engaged with the exhibits as well as what features included best captured their attention. The team used these features as inspiration in the design of the project.

4.5.1: Exhibit Types

Since the team's project is focused on biomechanics, science exhibitions were mostly the types of exhibits sought after. One area at the museum included observing how a ball follows a track by demonstrating concepts related to physics. There was one section in the museum that was completely dedicated to producing power with the muscles, including an area where children can pull themselves up into the air with a rope as seen in Figure 8. Another station had an air pump system that caused a ball to rise through a tube when force was applied to the seat. Since power was one of the possible biomechanical concepts the team wanted to display, this power station was helpful in understanding how well the children were engaging with the activities and what types of information the exhibits displayed. The team decided to use the air pump concept as part of the design as it is a good way to show immediate effects.

Figure 8. Photos of team members at the Boston Children's Museum

4.5.2: The Importance of Visual Attractiveness

One of the most prominent aspects of this museum was the use of colors. Walls, signs, and play areas were designed using bright and attractive colors. Lights and sounds were also frequently used, which helped draw the children's attention to those specific areas. Black lights were used on some displays, and one area used sensors to play a splash sound when you stepped on a lilypad that was projected on the floor. The most attractive areas seemed to have the highest number of visitors, so the team realized that the visual attractiveness of the project was going to be a major consideration to encourage people to use the model.

4.5.3: Other Key Takeaways

One of the most important takeaways of this trip was the small size of the exhibits. Touch stations were low to the ground so children would be able to easily reach them. The team realized that they also needed to be mindful of making things child-sized so that children would be able to reach and interact with the design. The activities were very intuitive and the children were often able to still complete the task without needing to read instructions or have a chaperone. Another big observation the team discovered was that many of the exhibits provide immediate feedback on what the child was doing. This confirmed that the specification of quick feedback would also be important.

4.6: Final Design Selection

The foundation for the final design selection of the model was first outlined in our design requirements and the research in educational models to keep kids engaged. Requirements generated for the model were used to filter out preliminary concepts through brainstorming and a Pugh Analysis. The Pugh Analysis shown in Figure 9 shows that jumping was the highest-ranked idea when compared with our secondary objectives. The cons of the other models also contributed to their elimination. The necessary components of the model were then used to create a final design that was able to fit the criteria established.

Objectives	Weight	Bone Breaking		Skeleton model		Softball		Jumping	
Durability	**5**	1	5	1	5	0.5	2.5	1	5
Active Participation	**5**	1	5	1	5	1	5	1	5
Draw Curiosity	**4.5**	1	4.5	1	4.5	0.5	2.25	1	4.5
Ability to Play with the Model	**5**	1	5	1	5	1	5	1	5
Passive Learning	**4**	1	4	1	4	0	0	1	4
Type of Visuals Used	**5**	1	5	0.5	2.5	0.5	2.5	1	5
Involving Senses	**4**	1	4	1	4	1	4	1	4
Relevant Information	**3.5**	1	3.5	1	3.5	0.5	1.75	1	3.5
Size of Demonstration	**3**	1	3	1	3	0	0	1	3
Response Time	**4**	1	4	0	0	0.5	2	1	4
Session Reset	**4**	1	4	0	0	0.5	2	1	4
Response Accuracy	**2**	0.5	1	0.5	1	0	0	1	2
Compactability	**3**	0.5	1.5	1	3	0	0	1	3
Easy to Move	**3**	0.5	1.5	1	3	0	0	1	3
Cost Efficient	**1**	0	0	1	1	1	1	0.5	0.5
Total			51		44.5		28		55.5

Figure 9. Pugh Analysis of the four preliminary designs using the secondary objectives

4.6.1: Force Sensors Selection

The force sensors were selected by the team through testing and research comparing all different types of sensors to weigh the advantages and disadvantages of each kind of sensor. The functionality of the sensors is crucial to be able to display data promptly and therefore provide feedback to the participant. Ultimately the team decided that the best sensors to test on our model are Force Sensitive Resistors and Load Cells as both output a result that, through coding, can be converted into force production, jump height, and power. The team decided to use load cells instead of the force-sensitive resistors since the load cells were more accurate in detecting changes in force during initial testing.

4.6.2: Final Conceptual Design

After careful consideration of each part that composes the model, a final design was outlined. The goal for the final design was to demonstrate biomechanical concepts that occur when jumping on a platform. The final design was split into two main parts that were both important to the overall design. The first section of the model measured the jump height of the participant, as it simulated a Vertec jump test. This section consisted of the base, telescoping tubing for easy height adjustment, and rungs for a visual representation of jump height. The second section of the model displayed data using the load cells selected and gave immediate feedback through air pumps that launched a ball to help show the effects of the force and power that the person jumping produced. This part of the model included a sandwich-like assembly where seven air pumps sat in between two wooden boards that had sensors installed in them. The tubing from the air pumps fed into the main 90-degree clear tube assembly where the ball sat, and after air was released the ball was then launched.

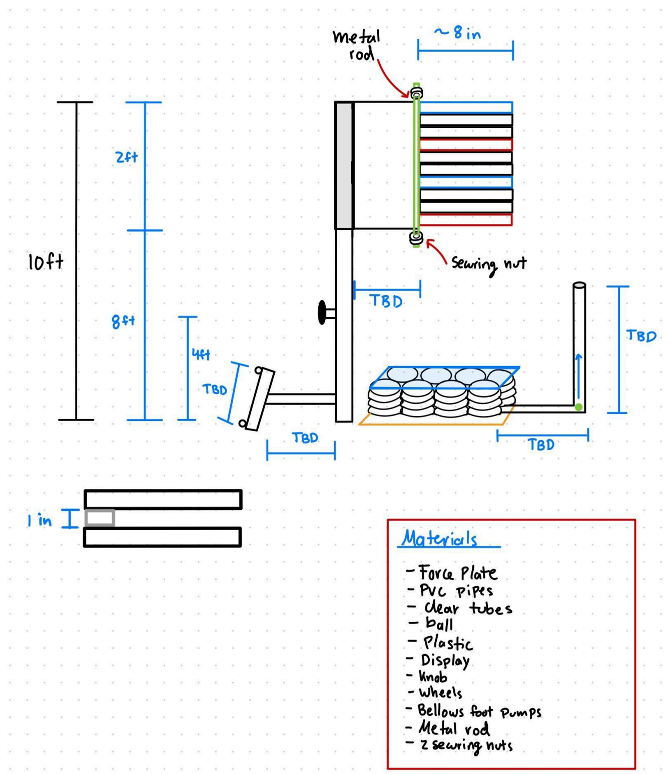


Figure 10. Conceptual drawing of the final design

4.7: Design Calculations and Modeling

The total height of the jump test was calculated by using an anthropometric data table. The team assumed that the tallest user would be in the 14-year-old range. Through the growth charts developed by the CDC, the average height of a 14-year-old was obtained [12]. The arm length was calculated by multiplying the average height previously obtained and the segment length of the total arm acquired in the anthropometric table [13]. Another assumption made is that when the user's arm is raised straight above their head the remaining length from the head to the ulnar styloid is about half of the total arm length. After obtaining the total height the team decided to make the height of the model 10 ft, with adjustable tubing to lower it to 4 ft. This will allow all participants to use the model adequately and avoid any ethical concerns.

$$Average\ 14\ y/o\ =\ 69.5\ in$$
$$Segment\ Length\ of\ Total\ Arm\ =\ 0.530$$
$$Total\ Arm\ Length\ =\ 69.5\ in\ (0.530)\ =\ 36.835\ in$$
$$Arm\ Length\ Above\ Head\ =\ \frac{36.835\ in}{2} =\ 18.4175\ in$$
$$Total\ Height\ +\ Arm\ Length\ =\ 69.5\ in\ +\ 18.4175\ in\ =\ 87.9175\ in\ =\ 7.326\ ft$$

Chapter 5: Design Verification

The content of this section encompasses the results of the design and how it was taken into account for further verification. To ensure that the full apparatus would work and generate results, the team separated the model into different components that were designed and continually tested.

5.1: Design Development

The following section details the development of each component of the final design and the mechanisms the team selected for each part. The major components of the model are the air pump mechanism, ball and tube mechanism, vertical jump stand and rungs, and load cells. The team initially used Solidworks to design the components of the design and assembled them into a full apparatus, shown below in Figures 11 and 12. Figure 11 is the initial brainstorming concept while Figure 12 is the final design. The digital model provided a template for the selection of materials and prototyping.

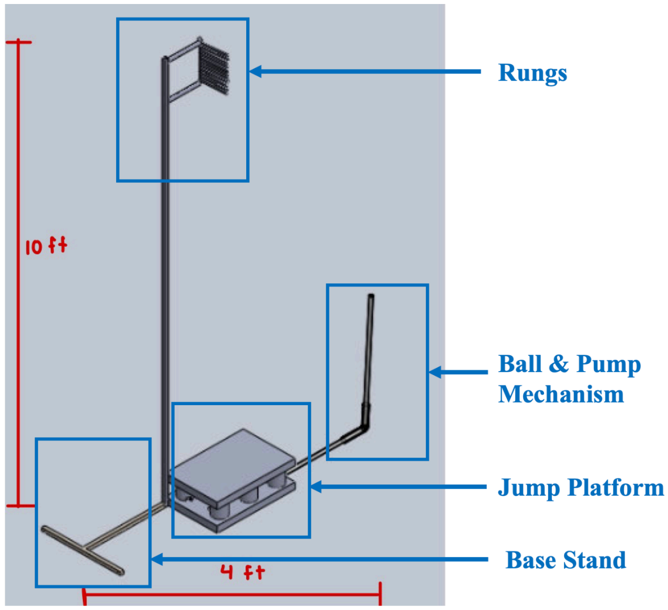


Figure 11. Labeled CAD assembly of the full prototype before fabrication

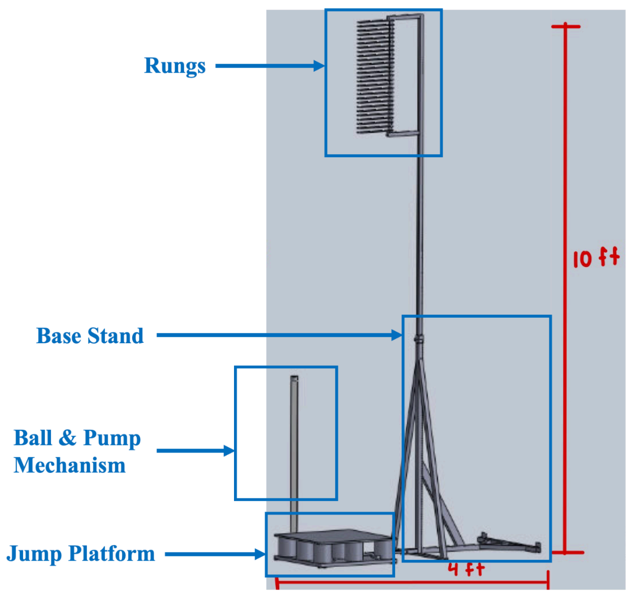


Figure 12. Labeled CAD assembly of the full apparatus after fabrication

5.1.1: Air Pump Mechanism

The base of the model originally consisted of manual air pumps placed in between two wooden boards as seen in Figure 13. However, due to warping and the heavy weight of the boards, they were replaced with ½-inch thick polycarbonate sheets. The sheets that sit on top and below the air pumps were required to be sturdy enough to withstand the force of a person jumping repeatedly, but not heavy enough to permanently depress the air pumps. Polycarbonate was a good selection because of its light weight while having a tensile modulus of 377 GPa [16]. The design originally used six air pumps placed in two parallel columns of three each so that the force of each foot could be evenly distributed.

After initial testing, one additional pump was added to the center edge to provide added stability to the base and to strengthen the efficiency of air pumps when inflating. To ensure that the air pumps and boards did not shift when the model was in use, hook and loop fasteners seen in Figure 14 were attached to each touching point on both the top and bottom of the air pumps. Hook and loop fasteners were chosen as they allowed for both easy removal and attachment. The tubing of the air pumps was oriented inward to promote safety as the component was localized. The air pump tubing was fed into an acrylic tube to connect to the ball and tube mechanism.

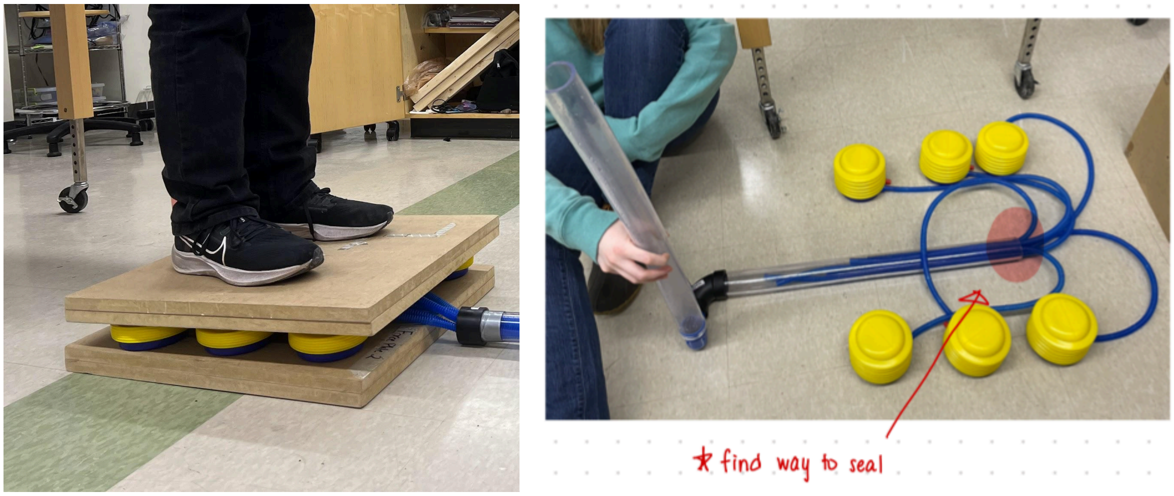


Figure 13. First Prototype for Air Pump Mechanism

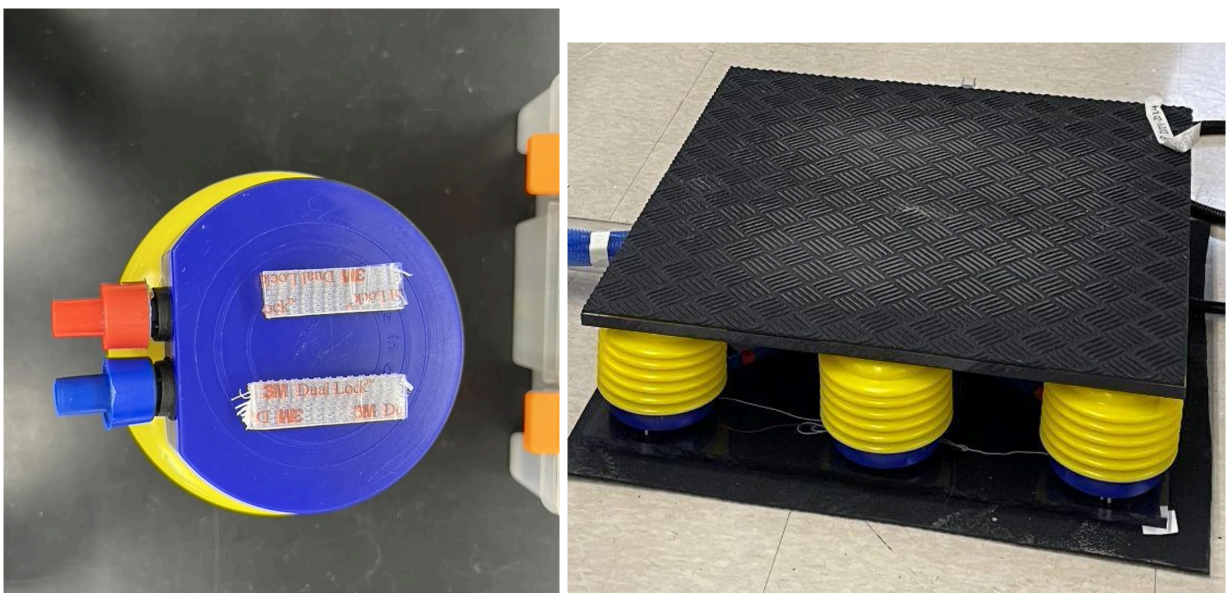


Figure 14. Hook and loop fasteners on air pump (left) and revised jump platform with air pump mechanism (right)

During the initial tests of the pump mechanism, the team noticed that the jumping platform felt uneven when standing on it due to the air pumps below. Additionally, the team noticed a risk of damage to the sandwiched acrylic tube if the polycarbonate boards were to be compressed too forcefully. Stoppers, as seen in Figure 15, were placed between the boards to mitigate any extreme force. The stoppers were placed near the perimeter of the board and at a height that would allow the air pumps to still compress and decompress, but prevent the board from crushing the acrylic tube.

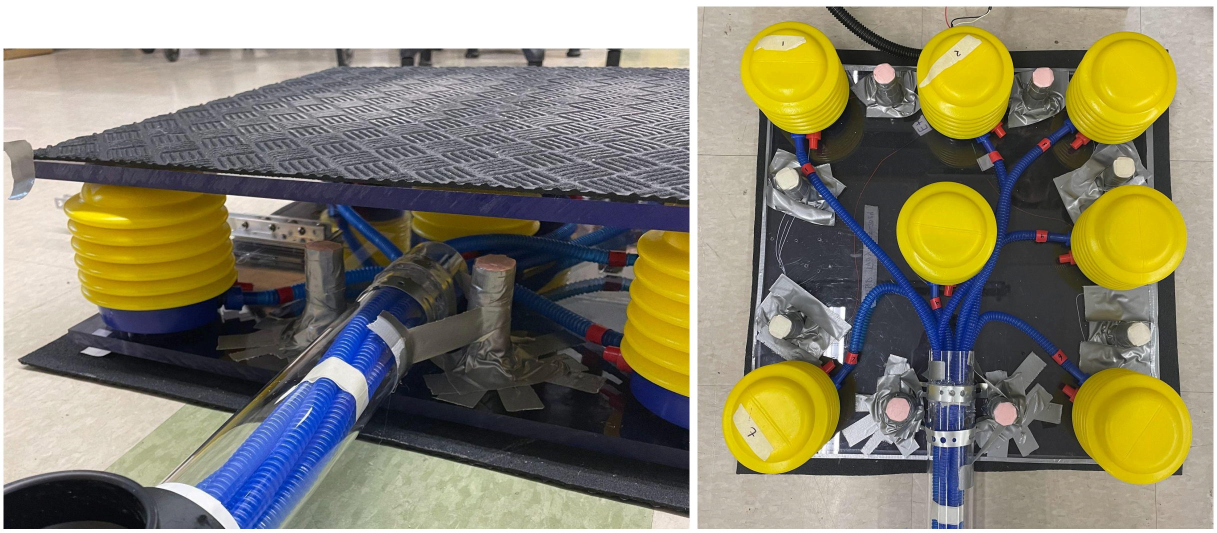


Figure 15. Final version of the pump mechanism with the addition of stoppers on all sides of the jump platform

5.1.2: Ball and Tube Mechanism

The second component of the apparatus incorporated a visual element of a ball that was connected to the air pump mechanism. The design included clear, acrylic tubing and adaptors that connected to the air pumps with a ball positioned at the base of the air pump mechanism. Acrylic was chosen over vinyl tubing for its rigid structure. Vinyl tubes warped after some time and this affected the vertical ball path. The acrylic tubing also had a larger inner diameter and a ping pong ball was able to fit inside. Upon landing on the air pumps, the applied force generated airflow, propelling the ball upwards through the tubing. To enhance the efficiency of the system, a layer of adhesive was applied to secure the ends of the tubing, ensuring a snug fit for the ball within the adapters and preventing any loss of airflow. The ball and tube mechanism was also drilled into the jump platform to keep it in place.

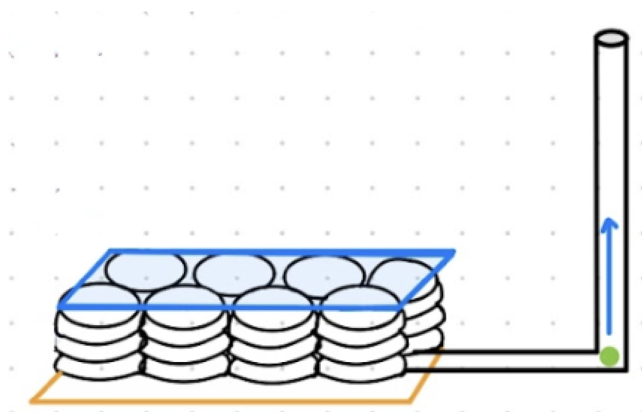


Figure 16. Drawing of the Ball and Tube Mechanism

Figure 17. Assembled Acrylic tubing

There was a risk of the ball falling into a different position at the bottom of the vertical tubing. A net was created with two parallel strips of tape to keep the ping pong ball from falling too far down into the tubing. Testing validated that the tape did not restrict airflow and helped the ball return to the same starting position after each jump.

Testing of the ball and tube mechanism yielded varying results over time. There were instances when the ball did not rise through the tube when the platform was jumped on. During other trials, the ball would rise slightly and spin. The team recognized that the air produced from the pumps needed to be better utilized and directed. The blue tubing connected to each air pump was lengthened so that it could be situated more vertically inside the tubing instead of ending at the angled corner piece. A funnel was placed upside down where the blue tubing ended to further channel the air flow. The ping pong ball rested on top of the funnel. The team tested again with the acrylic tubing. Over time, this generated a vacuum and the ping pong ball barely rose upwards.

The team decided to replace the acrylic tubing with wire mesh as seen in Figure 18. The funnel was kept, and metal wire mesh was wrapped around the funnel and ball. This open mesh helped prevent a vacuum, and the ping pong ball rose more consistently for each jump. Wooden sticks were placed around the perimeter of the tubing. The sticks were angled slightly inward to help guide the ball back into the same position after every jump. A photo of this setup can be seen in Figure 18.

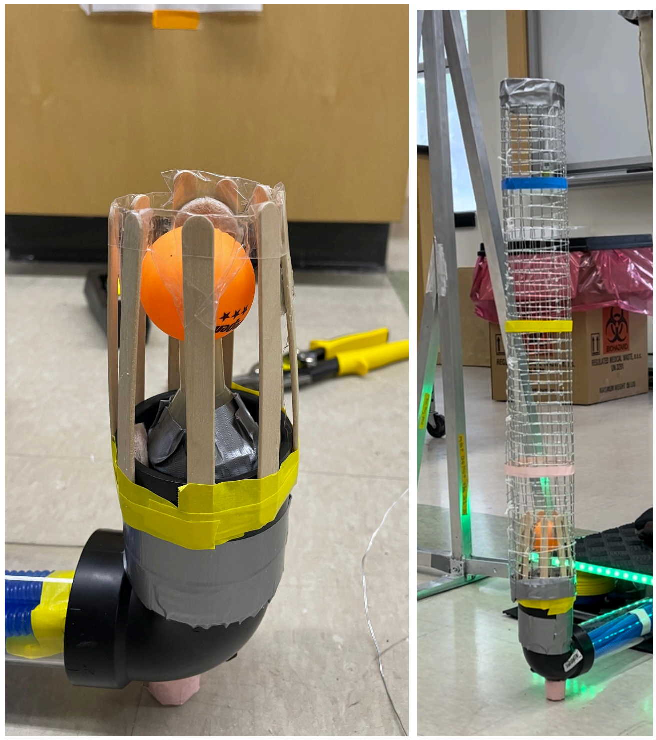


Figure 18. Ball pump mechanism with the angled wooden sticks (left) and wire mesh (right)

5.1.3: Vertical Jump Stand

The vertical jump stand was located on the right side of the platform from the ball and tube mechanism. To accommodate various heights and jumping capabilities, the vertical jump stand was adjustable. Aluminum square telescoping tubes were selected for the stand because this allowed for height flexibility. Using a plastic telescopic locking system, the height of the stand was adjustable to any height between 4 to 10 feet.

Since the rungs of the vertical jump stand would be repeatedly hit with force during the demonstration, a sturdy structure was required for overall safety. The vertical stand was connected to the base using rivets. A dowel was also attached to the base to mark where weights were to be placed. The weights were necessary to balance out the opposing weight of the rungs and minimize the risk of tipping. The jumping platform was attached to the vertical stand and base using a C-channel and a star knob. The star knob was securely tightened, but having a knob allowed for future detachment and portability. Finally, to meet the design objective of portability, wheels were attached to the base of the stand.

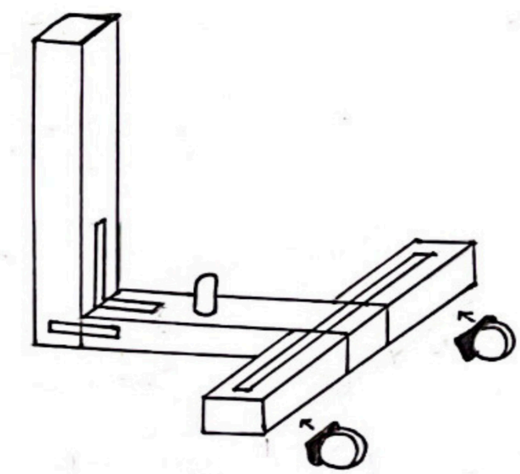


Figure 19. Prototype drawing of the vertical jump stand and base

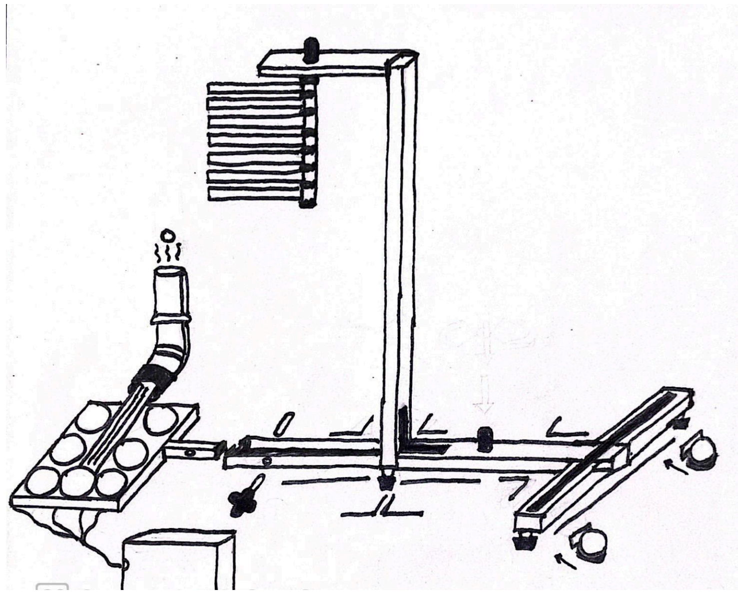


Figure 20. Initial drawing of the entire assembly

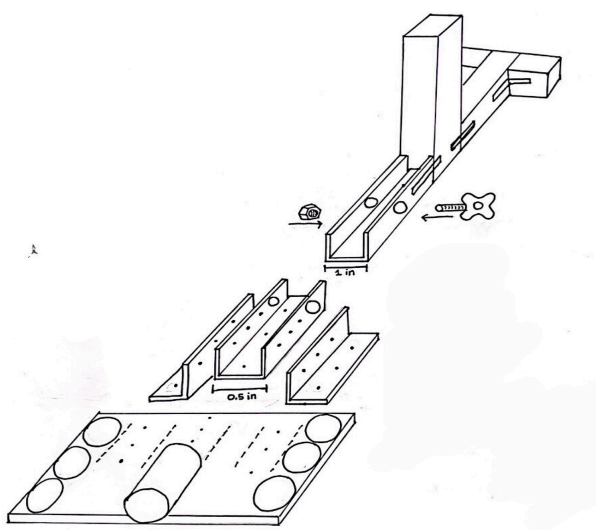


Figure 21. Initial drawing of the connection between the jumping platform and the base

Initial tests indicated that the vertical jump stand was not able to endure strong forces due to the lightweight properties of aluminum. Although the base was weighted, the vertical jump stand was still unsteady when the rungs were hit. To add more support to the vertical section, lateral supports were welded to the main aluminum tube, shown in Figure 22. Follow-up testing of the full apparatus validated that the addition of the support pieces assisted in a structure that remained stable when exposed to external force.

Figure 22. Initial assembly of the vertical jump stand (left) and the stand with extra supports (right)

5.1.4: Rungs

The function of the rungs was to be a visual aid of jump height since the rungs would move when hit. Plastic rungs were purchased and placed along a PVC pipe with 3⁄4 inch spacers in between each rung. Plastic rungs were chosen because of their lightweight material and color combinations. After assembling the rungs, they were spinning too freely and therefore, masking tape was applied underneath each rung to create friction while still allowing for some movement during use. To attach the rungs to the frame, a hole large enough for the pipe was cut into the aluminum and was secured using hot glue. Further testing indicated that the addition of tape did improve friction in the rungs and they moved with an acceptable amount of force.

Initially, the pole of the rungs was designed to be connected to the frame by a single point on top, and the aluminum frame was also connected using minimal aluminum plates and rivets as shown in Figure 23.

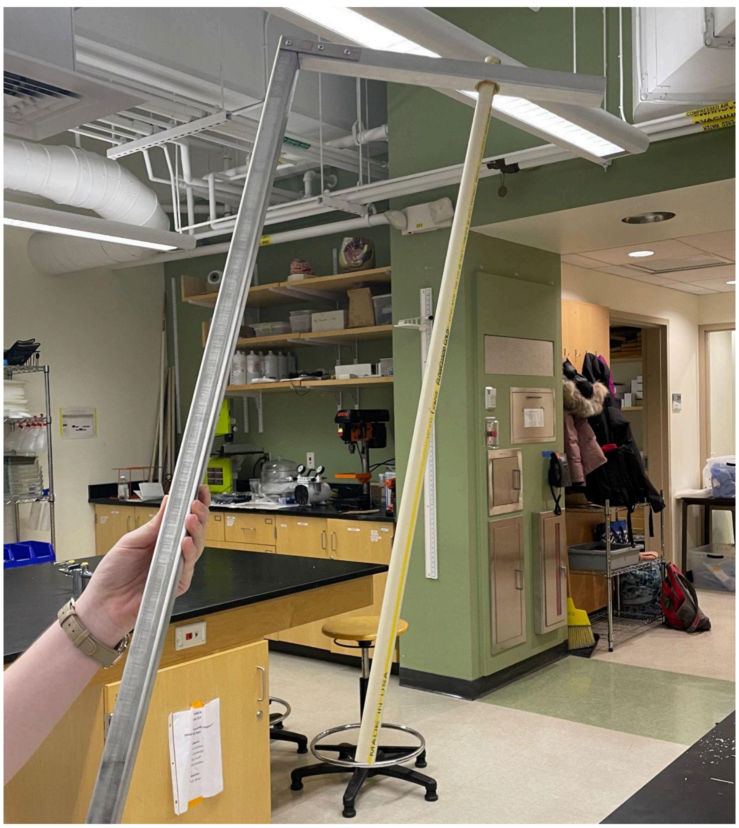


Figure 23. Initial design of rungs stand

The weight of the plastic rungs led to a slight cave in the frame. To create more support, a second horizontal bar was added to the bottom of the rungs to connect the vertical rod and the vertical stand. One bottom rung was removed to create space for the bottom aluminum support. Having two points of connection for the plastic pole ensured stability and a constant 90-degree angle with the frame. Through initial tests, the aluminum frame was found to be prone to shifting when the rungs were hit. A more supportive and sturdy frame was achieved using right-angle braces on each side of the top and bottom frames. Riveting plates onto the aluminum tubing was a permanent solution that ensured stability without future defects. The resulting design did not shift even when the rungs were being used in testing.

Figure 24. 90-degree angle supports for rungs stand

The space between the rungs and the vertical stand was made to be slightly shorter than the length of the rungs to avoid the risk of the rungs spinning too much after contact. This also allowed for easier resets of the rungs between demonstrations. There are three colored sections: red, blue, and white. The rungs were organized in color groups for visual contrast. The distance between each rung is ¾ inches with each colored section being a total of 4.5 inches.

Figure 25. Rungs before (left) and after (right) initial testing

To avoid damage to the rungs in the case of extreme force, strips of rubber padding were added to the vertical section of the aluminum frame. Rubber was chosen as the material would assist in absorbing the impact force and prevent the plastic rungs from shattering.

5.1.5: Load Cells and Arduino Uno

Attached to the underside of the platform were four 50kg load cells connected to an HX711 amplifier that was wired into an Arduino Uno. Pre-designed 3D-printed parts were created by Patrick Laidlaw to hold the load cells in place while taking accurate measurements. The 3D-printed pieces were drilled into the polycarbonate sheet so that one load cell was placed in each corner. Each load cell is wired so that the displacement caused by the weight applied corresponds to a certain voltage output which is converted into mass via MATLAB.

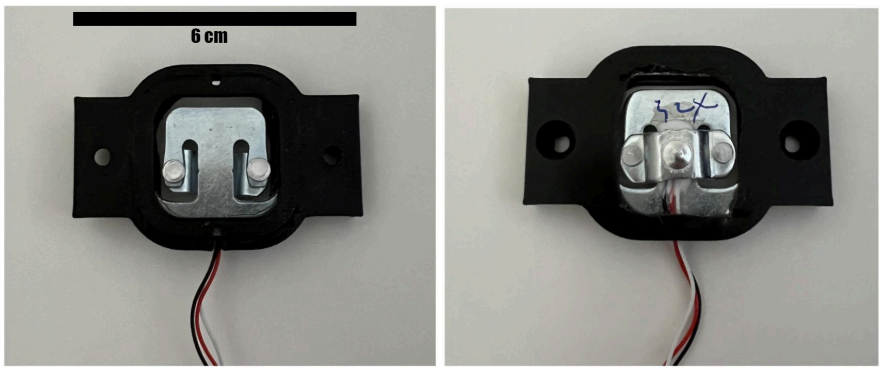


Figure 26. 3D-printed pieces that hold the load cells in place

The Arduino and breadboard were housed in a 3D-printed box for safekeeping and to protect the wiring. As seen in Figure 28, the box featured a hole for the wires to come out of, a hole for the USB port, and a sliding cover to easily take the Arduino in and out of the box if necessary. The cover also featured two holes for two buttons, one for calibration and one to start the program for the jump trial. The circuit diagram of how the load cells and buttons function can be seen in Figure 27. The Arduino needed to be placed roughly five feet away from the jumping platform to ensure that it would not be stepped on, so the existing wires connecting the load cells were soldered to longer wires. These wires were then placed in protective flex tubing.

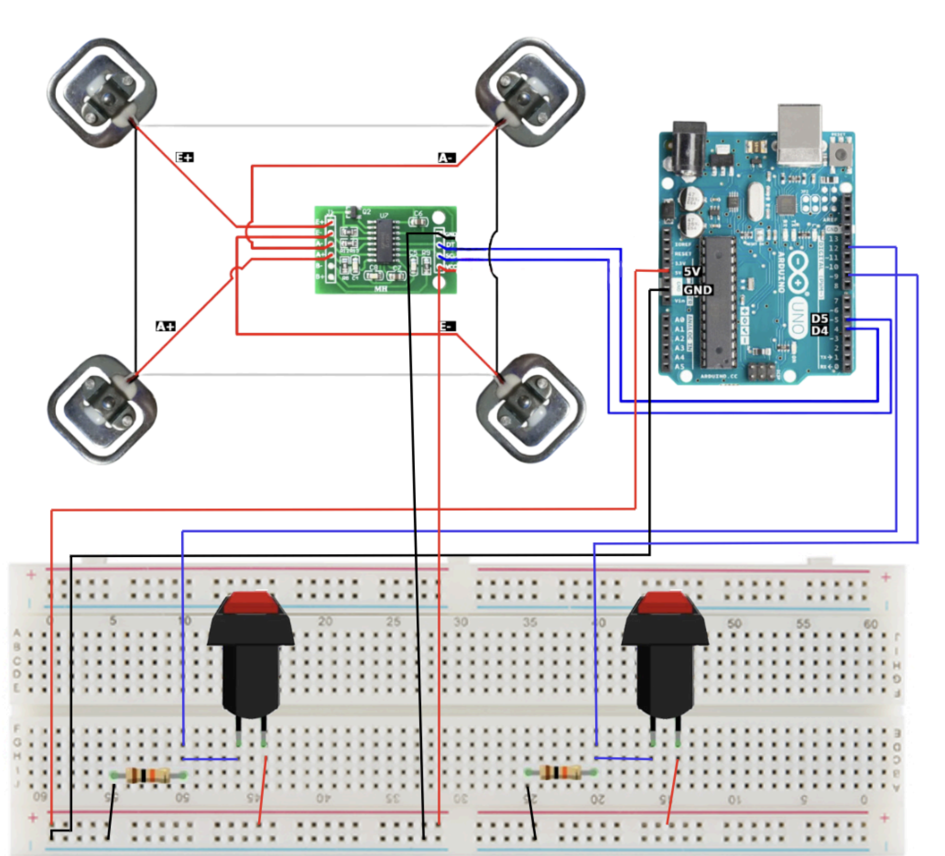


Figure 27. Circuit diagram of the load cells and Arduino Uno

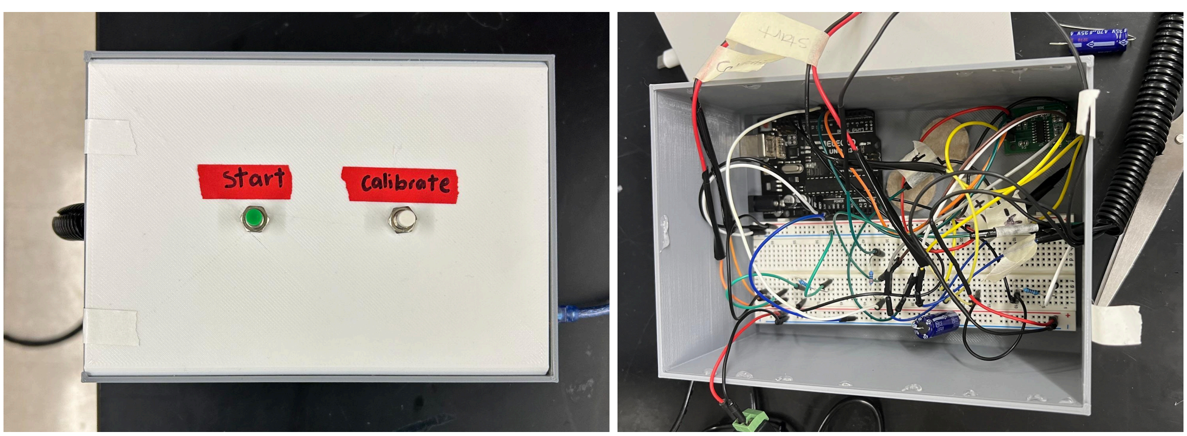


Figure 28. Assembled housing with all components inside

5.2: MATLAB Code

Using the GitHub repository created by Nicholas Giacoboni, the data sent by the load cells were easily translated into MATLAB for mathematical solving [18]. For each session, a script for the load cells to be calibrated was established. A calibration script was created by using known weight, scaling, and taring equations. Prompts were added to instruct the user on when to place and take off the weight. Figure 29 shows part of the calibration script used to accurately measure the weight of any object.

```
 %% Place 10Lb plate for calibration
 disp('Place known weight')
 pause(2)
 disp('Press button to calibrate')
while cal_button_status == 0
 cal_button_status = readDigitalPin(a,cal_button);
  if cal_button_status == 1
 % Change second number to known weight in grams
 cal = calibration(100, 52163);
 break
  else

  end
end
 %% Take off 10Lb plate for taring
 disp('Take off known weight')
 pause(2)
 cal_button_status = readDigitalPin(a,cal_button);
   % Prompt user to proceed to tare
 disp('Press button to tare')
 while cal_button_status == 0
  cal_button_status = readDigitalPin(a,cal_button);
   if cal_button_status == 1
 disp('Please wait...')
 tare(cal, LoadCell);
 break
   else

   end
```

Figure 29. Calibration script

Next, a program was created to generate a force vs. time graph for the forces produced during a jump, as well as display the calculated values from the trial. These calculated values were the flight time, jump height, velocity, force, power, and impulse. A time interval was created and the force readings during the time intervals were stored in a matrix. A force vs. time graph was then produced from this matrix. Figure 30 shows how the data was collected using a for-loop and how the matrix was initialized beforehand for storing the force readings and time stamps.

```
time = 0:0.022:4.4;  % Vectorized time calculation (Starts at 0s and ends at 4.6s at 0.022s intervals)

% Initialize the matrix to store time and force readings
forceMatrix = zeros(2, length(time));

% Iterate over time and acquire data
for i = 1:201
    % Acquire data
    mass = get_weight(cal, LoadCell);
    forceMatrix(2, i) = (mass / 1000) * 9.81;
    forceMatrix(1, i) = time(i);
    % Plot data continuously
    plot(forceMatrix(1, :), forceMatrix(2, :));
    drawnow; % Update plot
end
    xlabel('Time (s)');
    ylabel('Force (N)');
    title('Force vs Time', 'FontSize', 18);
    grid on;
```

Figure 30. Data collection code for the force vs. time script

The code to produce the graph was initially tested using a setup of a 10 lb weight, plywood, and load cells. A picture of the testing set up can be seen in Figure 31 below. To simulate a jump, the 10 lb weight was lifted off the platform, and then placed back on. This mimicked a person jumping since there should not be a force reading while the person is in the air. The code accurately read 10 lbs while the plate was resting on the platform and read a force of zero when the plate was taken off. This determined that the load cells were wired and responding correctly. A picture of the force vs. time graph produced during this testing can be seen below in Figure 32.

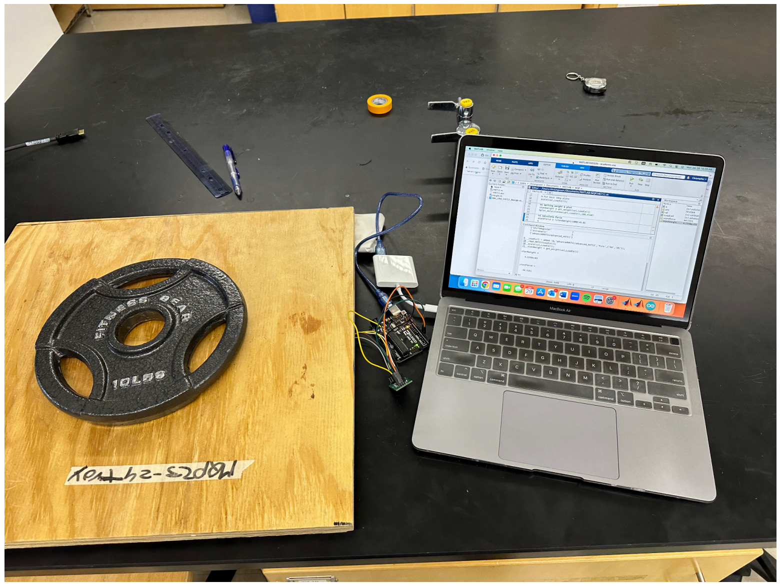


Figure 31. Initial testing setup using a 10 lb plate

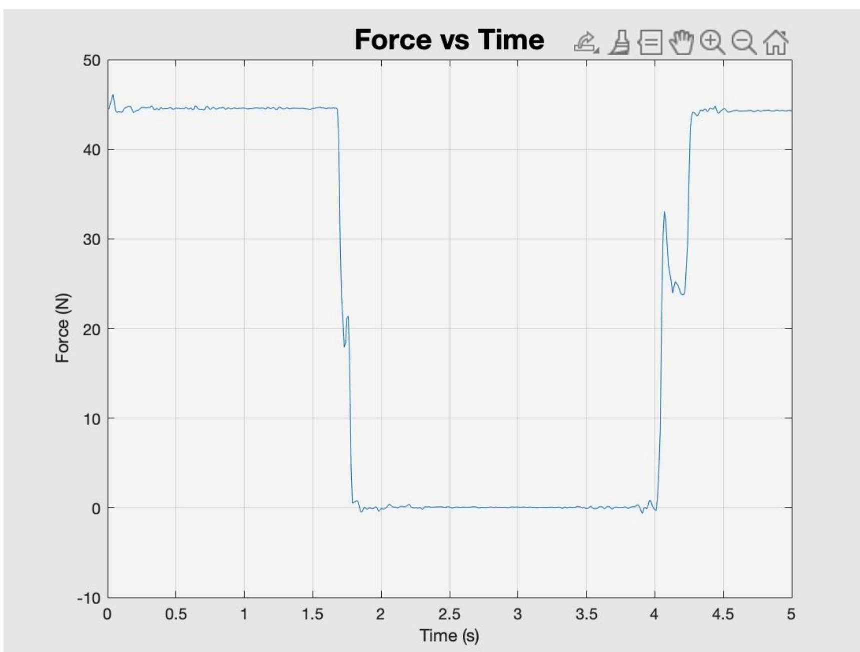


Figure 32. Simulation force vs time graph for 10 lb plate

Initially the force vs. time graph was taking on average 45 seconds to generate and display on the screen. A quick feedback time was one of the team's important design requirements, so this time needed to be shortened. Therefore the code was optimized using different combinations of time intervals and sampling rate to make the function run faster and be able to give immediate feedback to the user by creating the graph in real-time.

After the code was developed, two buttons were introduced to help segment the code and only allow one-time calibration and unlimited jumps. Additionally, LED strips were added to the platform to assist with visual attractiveness by working simultaneously with the scripts. To be able to incorporate the buttons and LED strips to the existing code, the team modified the existing scripts into functions and generated one larger function to call them all. In the button press function, the code defined the buttons and LED strips, based on their corresponding pin. The buttons were assigned a specific function that only ran when the button was pressed once. The calibration function used multiple while loops that continuously kept running until the calibration button was pressed to execute the calibration correctly. Following the calibration, a prompt appeared to tell the user to press another button to start the force vs. time function. The force vs. time analysis function in contrast used an infinite while loop, allowing the user to jump an infinite amount of times by repeatedly pressing the button or until the code was manually stopped. This allowed the user to no longer calibrate the code every time a new jump was performed. Finally, the LED strips were coded so that the colors changed depending on what part of the code was running. As shown in Figure 33, during calibration the strips first turned yellow indicating calibration had started. Then after calibration, the lights flash and turn green to indicate the platform is ready for jumping.

```
  %% Calibration loop until button press
  fprintf('Press the button to start calibration...\n');
   % If cal_button_status is not pressed loop will not initialize calibration
  while cal_button_status == 0
      cal_button_status = readDigitalPin(a, cal_button);
   % If cal_button_status is pressed loop initialize calibration
if cal_button_status == 1

  % Button pressed, start calibration
  fprintf('Button pressed. Starting calibration...\n');
  for i = 2:120
  % Change LED color to yellow
  writeColor(nstrip1, i-1, 'off', i, 'yellow');
  end
  for i = 1:119
      writeColor(nstrip1, 120-i, 'yellow')
  end

  cal = calibration_function(a, LoadCell);
  % Change LED color to green
  writeColor(nstrip1, 1:120, 'green');
  pause(1)
  % Turn off LED
  writeColor(nstrip1, 1:120, 'off');
  % Change LED color to green
  writeColor(nstrip1, 1:120, 'green');
  pause(1)
  % Turn off LED
  writeColor(nstrip1, 1:120, 'off');
  % Change LED color to green
  writeColor(nstrip1, 1:120, 'green');
  break
else

end
  end
```

Figure 33. Section of the button press function

5.3: Final Assembly

Once each component of the project was finished, the entire device was assembled together. Each component was checked to make sure that it fit together as intended. Felt furniture pads needed to be added to the bottom of the base to raise it to the same height as the platform. Extra pieces of metal also needed to be added to the bottom of the C-channel on the platform so it could more easily slide into the base of the vertical jump stand. To prevent slipping while standing or jumping on the polycarbonate sheet, a rubber mat was glued to the top of the platform. Another mat was placed on the floor to further prevent slipping. The figures below show the final assembly.

Figure 34. Full assembly with finalized components

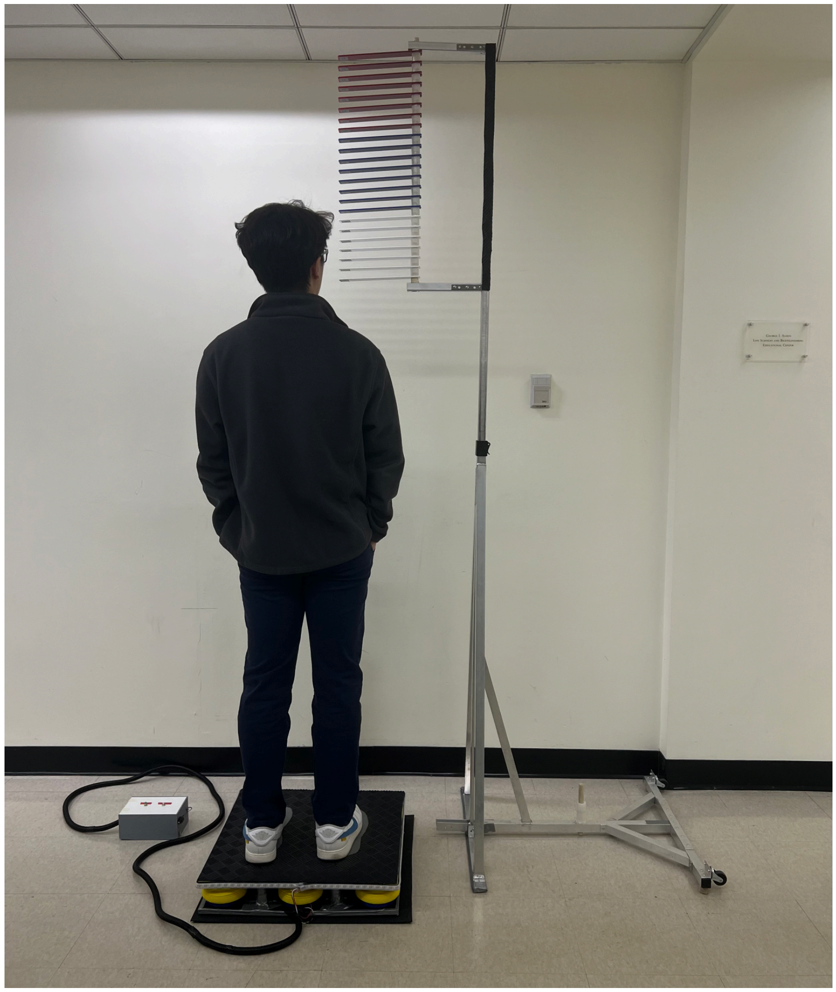


Figure 35. Full assembly with finalized components. The subject is 5’7” for reference

Chapter 6: Design Validation

6.1: Initial Validation Testing

Initial validation testing was performed by members of the project team. This was done to ensure that the different parts of the device were functioning properly as one component. The MATLAB code was modified intensively as team members jumped on the platform to accurately measure values similar to industrial standards. Based on this testing, changes to the design were made as described in the following sections.

6.1.1: Testing the MATLAB Code

Following the assembly and coding of the platform, testing was performed to determine if the calculated values were realistic. Figure 36 shows all of the initial calculated values using the force and time data gathered during a jump trial while Figure 37 shows the graph of force vs. time from that data. Jump height was calculated using flight time while the other values were calculated using the impulse-momentum theorem. The data showed that initially the values were not realistic, especially the impulse and force produced. When looking into why these values were not reasonable, it was determined that the air pumps absorbed some of the impact on takeoff and landing thus lowering the amount of force transmitted onto the load cells. In response, the jump impulse was now calculated as the total positive impulse from the entire jump because it resulted in more realistic values. Figure 38 shows how the new values were displayed after implementing this calculation and Figure 39 is the associated graph with that data. When compared to data from the rungs, it was reasonably close because the jump height difference was approximately 2 inches or less each jump. Considering that the platform measured the change in center of mass height while the rungs measured the reach height, the values were not exactly identical.

```
Change in time: 0.20 seconds
Jump Height: 0.05 meters
Velocity : 0.98 m/s
Jump Impulse: 71.13 Ns
Force produced: 29.64 N
Power produced: 30.71 W
New height: 0.05 m
Force vs time analysis complete!
```

Figure 36. Initial data results from testing

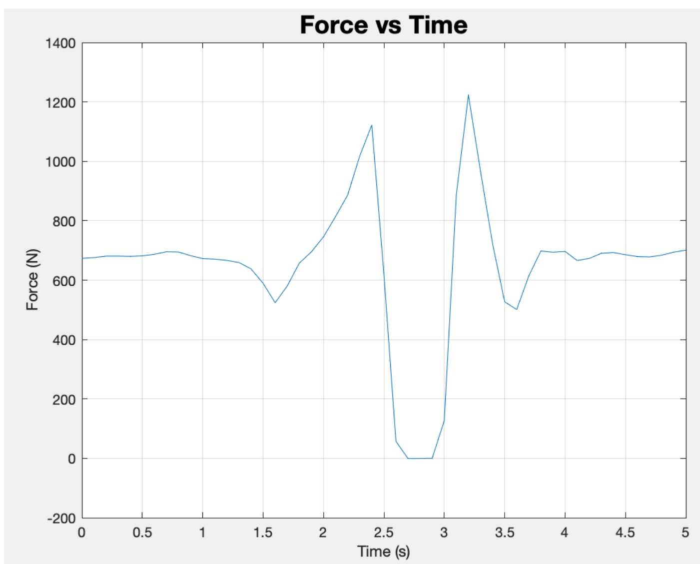


Figure 37. Initial force vs. time graph of data from testing

Figure 38. Final display of key statistics from a jump

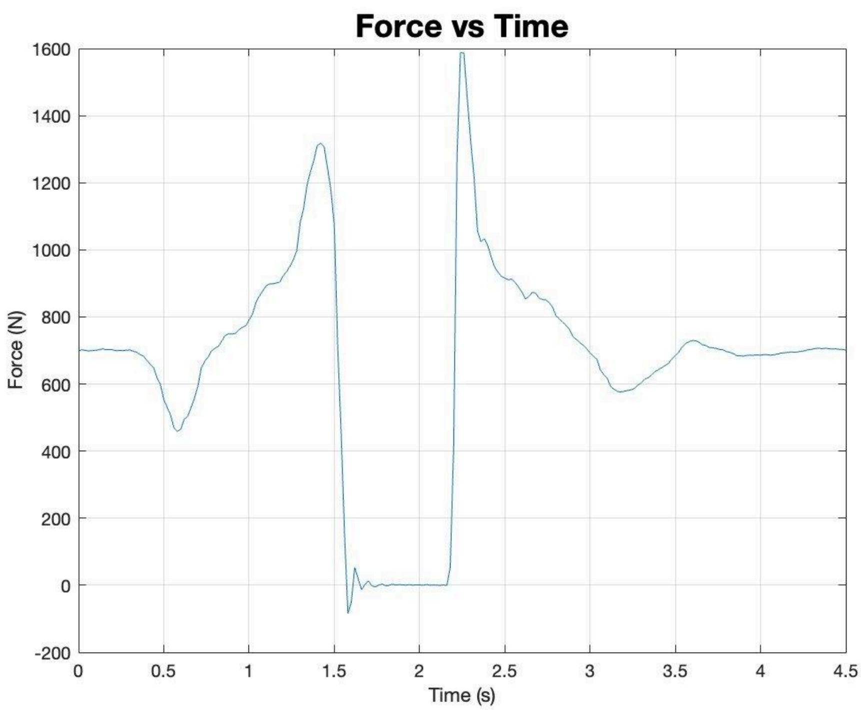


Figure 39. Final force vs. time graph of data from testing

6.1.2: Testing with AMTI Force Plate

Following the testing with the jump platform, the team wanted to verify that the data from the load cells was reasonably accurate by comparing the data to a more accurate force plate. Using an AMTI force plate, a jump was performed by the same person and produced a graph shown in Figure 40 and key statistics from the same jump in Figure 41. For reference, the sampling rate of the AMTI force plate was set at 200 Hz.

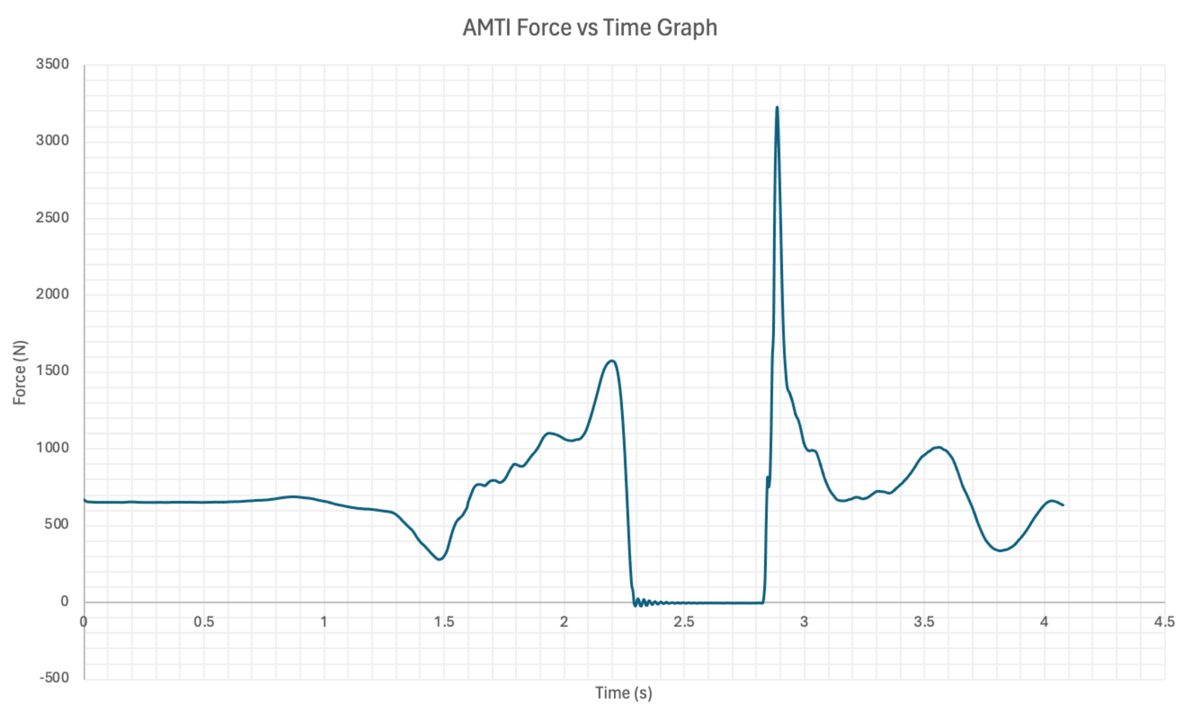


Figure 40. AMTI Force vs. Time Graph

AMTI Data	
Impulse	178.17 Ns
Velocity	2.66 m/s
Jump Height	14.2 in
Flight Time	0.535 s

Figure 41. AMTI Data

Our data using the new technique fell outside the 95% confidence interval and troubleshooting occured to understand why our data was not properly giving us data close to an accurate force plate. Upon further inspection, the HX711 amplifier was defaulted to 10 Hz rather than 80 Hz. Figure 42 shows two HX711 amplifiers with one set at 10 Hz and the other at 80 Hz.

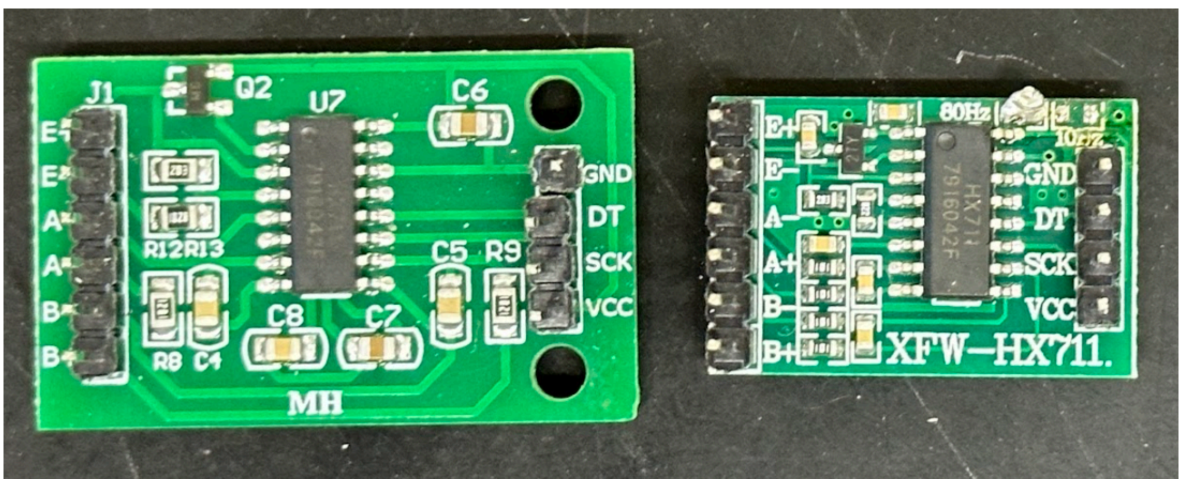


Figure 42. 10 Hz HX711 amplifier (left) and 80 Hz HX711 amplifier (right)

A faster sampling rate meant more data points and increased accuracy of the calculations. The one minor caveat with data collection is when the code is continuously plotting the data, there is going to be a latency in collecting data. Therefore after optimizing the code once more, the data collection was at 50 Hz which was still five times faster than the initial testing. Figures 43, 44, and 45 are all paired T-test results that looked at the 50 Hz sampling frequency of our platform and compared that with the AMTI data. All figures showed that the values from our platform were not statistically significant and fell inside the 95% confidence interval meaning our platform and the AMTI show very little difference between each other in recording and calculating data.

Paired T-test for Flight Time		
Group	**AMTI Flight Time (s)**	**Our Platform Flight Time (s)**
Mean	0.533	0.58667
SD	0.02255	0.0611
SEM	0.01302	0.0353
N	3	3
Two-tailed P value	0.3524	Not statistically significant
95% Confidence	-0.24428 to 0.13761	

Figure 43. Paired t-test results for flight time

Paired T-test for Velocity		
Group	**AMTI Velocity (m/s)**	**Our Platform Velocity (m/s)**
Mean	2.7067	2.63
SD	0.0569	0.6864
SEM	0.0328	0.3963
N	3	3
Two-tailed P value	0.8559	Not statistically significant
95% Confidence	-1.5256 to 1.6790	

Figure 44. Paired t-test results for velocity

Paired T-test for Jump Height		
Group	**AMTI Jump Height (in)**	**Our Platform Jump Height (in)**
Mean	14.7067	14.5
SD	0.6673	7.3466
SEM	0.3852	4.2416
N	3	3
Two-tailed P value	0.9628	Not statistically significant
95% Confidence	-16.7015 to 17.1148	

Figure 45. Paired t-test results for jump height

6.1.2: Testing the Ball Mechanism

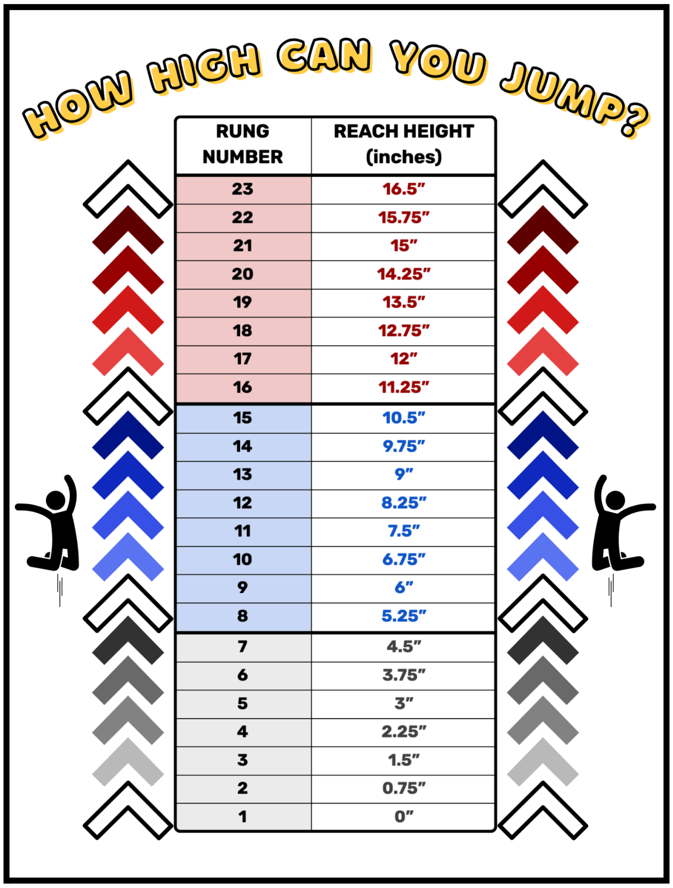
Validation testing of the ball mechanism was performed once the ball mechanism was fully assembled and connected to the jump platform. Testing was done to ensure that the mechanism was successful in functioning as a visual aid for jump power by causing the ball to rise inside the tube when the jump platform was used. The woven wire mesh was successful in acting as a barrier and path for the ball without creating an air vacuum, so the ball was able to travel in a vertical direction. Additionally, the tube was still visually appealing with the three distinguishable color stripes. The cone at the base of the ball mechanism was successful in slightly directing the airflow of the tubes and resetting the ball in a consistent position. The cone also successfully prevented the ball from falling too far back into the air tubes.

6.1.3: Testing the Vertical Jump Stand

Following the assembly of the vertical jump stand, rungs, and jumping platform, testing was performed to validate the functions of the assembly. When the rungs were hit, the full base stand wobbled due to the force, but movement was minimal and the stand did not tip over. The weights on the base of the stand ensured that the weight throughout the full model was evenly distributed. The welded supports also ensured even weight distribution throughout the stand, minimizing the risk of tipping and twisting in the vertical stand. The height of the rungs was easy to adjust using the locking mechanism of the aluminum tube. The wheels were successful in allowing for portability of a large model.

6.1.3: Testing the Rungs

The rung system was tested to validate that the rungs moved upon contact and were able to withstand constant use. The rungs were found to be stiff due to the tape underneath the spacer. The rungs were repeatedly swung to help reduce some of this friction. Further testing also included hitting the rungs with excessive force, causing the rungs to swing for the full range of motion. In this case, the rungs successfully moved and bounced off of the rubber padding without any damage. Validation testing revolved around ensuring that the rungs moved when hit and staying stable and durable with constant use. Testing indicated that the rungs did move to indicate jump height. The tests also indicated that the rungs system did not incur any damages throughout the processes. The relation between the rungs and the height reached was incorporated into a chart for a visual aid, seen in Figure 46. The increments between each rung were measured to be accurate and consistent with the chart.



RUNG NUMBER	REACH HEIGHT (inches)
23	16.5"
22	15.75"
21	15"
20	14.25"
19	13.5"
18	12.75"
17	12"
16	11.25"
15	10.5"
14	9.75"
13	9"
12	8.25"
11	7.5"
10	6.75"
9	6"
8	5.25"
7	4.5"
6	3.75"
5	3"
4	2.25"
3	1.5"
2	0.75"
1	0"

Figure 46. Rungs jump height chart

When the first few jumps were performed with the whole apparatus, the team noticed that it was difficult to watch the ball rise and hit the rungs at the same time. Focusing on hitting a higher rung resulted in less focus on producing lots of force and the ball did not rise as high. The team decided to separate the two components and remove the attachment of the stand from the platform. This allowed for the flexibility of moving the rungs so that people who wanted to jump on the platform without the rungs could do so easily. It also can be separated into two separate stations for groups that are large so there is less waiting time.

6.2: Testing Beyond the Project Team

To ensure that the device met the objectives, the team brought in a 6-year-old child to test the platform and rungs. This was conducted to help determine whether the device was safe and fun for the intended audience. Figure 47 shows this child jumping on the full apparatus.

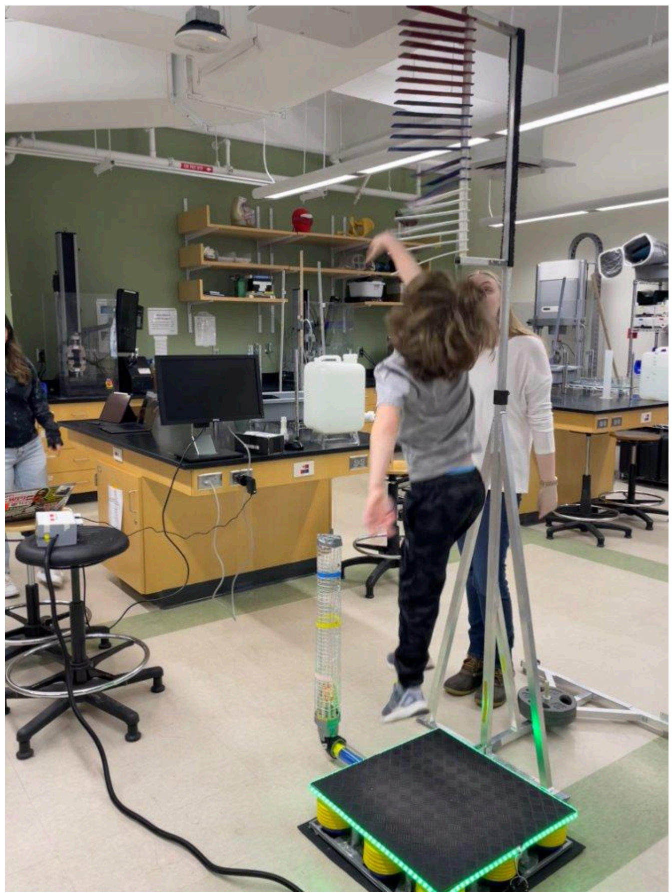


Figure 47. 6-year-old child using the device

After explaining how to properly jump beforehand, the child was most intrigued with the rungs and how easy it was to repeatedly hit them. When jumping on the platform, the code ran as intended and produced the correct graph and values, however, the child showed no interest in what they meant. There was a problem with the ball and air tube system in which the ping pong ball did not travel as far up as intended because of how little the child weighed. To solve this problem, balls of different weights ranging from styrofoam balls to duct-taped wrapped balls were introduced as a way for kids of different weights to get a more interactive result. The child also had a tendency to land on the platform unevenly and in different areas. To help prevent other children from doing this in the future, foot placement markers were created to help encourage children to jump with both feet in the center of the platform.

Figure 48. Different balls used depending on the child's weight

When finished testing, the child indicated that the best parts were the rungs and the LED lights on the platform.

6.3: Ethical Implications

Creating a biomechanics model that requires the engagement of the user demands a careful review of potential ethical implications including environmental, social, global, and economic issues.

6.3.1: Environmental

The model could have the possibility of using wood and any other natural resources that are taken from the environment. To combat this, man-made materials are preferable including metals and polycarbonate. Using metals and polycarbonate as alternatives for materials such as wood comes with environmental issues. These materials often require mining, which can lead to deforestation, loss of habitats, and water pollution, and also contribute to carbon emissions. Disposing of these materials that do not break down naturally creates issues in waste management with recycling and the potential for long-term harm to the environment.

6.3.2: Social

Using this device at outreach events will allow students who would maybe not normally learn about biomechanics to gain some knowledge about biomechanical concepts. By introducing biomechanics at a younger age, more students may become curious and decide to pursue higher education or employment in the biomechanics field later in life. While the target population is elementary and middle school students, the model is not limited to only that age range. Those who are in high school and even adults may also be able to learn while using the model. As the age range expands, so does the height range, which means the rung height was designed to be inclusive for most. Factors that may inhibit an individual's ability to participate may be a physical disability that does not allow for a movement that is required in the demonstration. Therefore, the model should accommodate as many abilities as possible. If someone is unable to fully interact with the model, the model should still be engaging for them and they should still feel that the model provides a learning experience. Adaptations could be made to the device so that those with disabilities can participate on some level. For example, someone who uses a wheelchair can have the option to punch something instead of jump. While this will not provide measurements of forces and power from a jump, the model will show the participant that the arm muscles can also produce power and forces. Since the device only currently involves visual aids, sounds can be incorporated for an interactive experience for those who are visually impaired. Additionally, the model may not be as accurate as the competitors, so users should be aware of the possibility of inaccurate numbers when interacting.

6.3.3: Global

Since biomechanics is a universal concept and impacts people of all different body types and age ranges, the results are relatable to users regardless of the country they interact with the device from. Calculated values should be in standard units to prevent confusion, or be updated to the units typically used in that country. Children from different backgrounds may not have a full understanding of English so the model should limit the amount of printed words and rely more on the interactive aspects and visual cues. If printed materials are needed, the device could display common languages for those who may have difficulty reading English. The materials and parts that are used in the model are within stock on a global market so that it can be reproduced in other countries. To share the design on a global scale, the model can be posted to online resources with public access. In other countries, the use of a computer or WiFi may not be readily available, so the device should be updated to be a stand-alone device that can function without a computer.

6.3.4: Economic

Our model should be low-cost so that anyone can reproduce it. However, there is also the consideration that if the model is cheaper, then the accuracy is reduced. If the device breaks, there is a risk of the device becoming no longer functional if the parts are not replaced. Since the device is not made from expensive materials and is therefore more likely to break than if higher-quality materials were used, the device should be as durable as possible to decrease the likelihood of parts needing to be thrown out and replaced. Gaining exposure to STEM through this device and other similar devices would cause more children to be interested in joining the field. This has economic benefits since it would grow the workforce by creating more job opportunities. The wealth of the field is further improved by more technologies being innovated due to the larger workforce.

6.3.5: User Safety

Finally, in any interactive biomedical model, it is essential to ensure adequate safety measures and proper supervision to uphold ethical standards and protect the well-being of the participants involved. Since the model will be taking real-time data the team has to ensure that the data collected by the model is only used for the intended purpose to avoid possible misuse. The risks of using the device are minimal. The device is not expected to fail under the expected loads, however injuries could occur if the user lands incorrectly.

Chapter 7: Discussion

7.1: National Biomechanics Day Demonstration

After successfully validating the rungs and platform, the team decided to test the device on the intended audience of elementary and middle-school children. This final demonstration would serve as the final benchmark on whether the team had created a device that met the original objectives. In collaboration with the Vernon Hill Elementary School in Worcester, Massachusetts, the team was able to put on a community outreach event for a group of approximately thirty 6th graders at the school. The two components of the model were on separate sides of the room, and the students were able to switch back and forth between the two. The students were able to interact with the device for about 30 minutes. Most children interacted with the device for the duration of their turn, which lasted around 30 seconds. They then either returned to the back of the line to complete another turn, or joined the line for the other component. Many children used both components multiple times. The children were excited to tell their classmates what number rung they hit and encouraged their friends to jump higher than their previous attempts. A worksheet was also created that asked the students to name muscles that are used when jumping, observe what happens when jumps are performed in different ways, and perform quick calculations related to jumping. The children quickly became disengaged with the worksheets and they were found scattered throughout the room. The worksheet can be seen in Appendix F. Figure 49 shows kids jumping on the platform and hitting the rungs separately.

Figure 49. 6th graders at Vernon Hill Elementary interacting with the device

7.2: Assessing Device Objectives

After testing with kids and performing a community outreach event, the team assessed the device using the original primary objectives. The team determined that the device was successful in meeting most of these criteria. The first objective was to make a device that was fun and engaging, and all participants indicated they had fun either through repetition or friendly competition. The next objective was to make the device interactive, and the kids were actively interacting with both the rungs and the platform. Following that, the next objective was to make the device visually attractive. Based on observed behaviors, the kids were impressed with the LED lights, bright pumps, and colorful rungs. Regarding the jump platform, they were able to recognize that the more force they landed with, the higher the ball went up. The educational objective was met through the statistics calculated from the code displayed on a monitor and the worksheet that was made for the outreach event. The quick measurements objective was satisfied through rapid results from each jump and kids being able to participate within 1 minute. Some students were interested in the software behind our device and proceeded to observe the code running while their classmates jumped. The durability objective was met since the jump platform and rungs were still functional after the outreach event. All of the components for the device could fit inside an SUV but required multiple people to handle them properly.

The team believes that this device would be successful at other outreach events. We recommend splitting the model into the jump platform and rungs, especially when there is a large group of children. The team recommends showing the children how to use the device safely before they are able to interact with it. A demonstration was given to the children at Vernon Hill, but more children entered the room after that demonstration. Those children quickly learned how to use the device from watching the first few children jump, but the team believes that performing a demonstration to the children all at once would better promote safety and reinforce the purpose of using the model. It may be best to use the device at smaller gatherings so that each student can interact with the model for a longer period of time. A large area of space should be available so the children can jump safely and not injure themselves or onlookers. Since the device currently needs a computer, it would be beneficial to place the device near an electrical outlet in the event that the computer battery runs low. Teacher or guardian involvement may also be beneficial to reinforce the biomechanical concepts. If worksheets are to be used in the future, it is important that the questions are asked in a way that is appropriate for the child's grade level. Guidance from teachers would also help in making sure the children complete the worksheet.

Chapter 8: Conclusions and Recommendations

8.1: Conclusions

In our everyday activities, we encounter biomechanics as it displays how our body reacts to forces, but these concepts are typically not introduced to students until high school or college. Today there are not many educational models that present biomechanics concepts to young children. Therefore, there is not enough exposure to these concepts earlier on that could spark curiosity and interest to inspire future generations to pursue a biomechanics career. Our device was a jumping platform to be used at outreach events that would teach children about the biomechanics behind jumping.

The device met most of the objectives well. The children who tested the device seemed to enjoy interacting with it. The children liked the visual aspects, repeatability, and almost all of the children tried to produce a better jump each time they used it. Splitting the device into two components, the rungs and jump platform, proved to be beneficial. It reduced the time the children needed to wait for their turn, as well as allowing the children to focus on one component at a time.

8.2: Future Recommendations

With the success of the National Biomechanics Day outreach event at Vernon Hill Elementary, the team concluded that the design of this model was successful in meeting the objectives indicated in the client statement, but could be improved in the future. The team recommends the following improvements:

- **Portability:** One of the important design criteria was that the device was portable so it could be taken to community outreach events. The design was successful in being portable, but it took four team members to carry the different components of the device out of the building and to a car. It also took some time to properly situate the components into the car, and the device would most likely not fit in a small vehicle. To improve portability, the components of the device could be separated and assembled at the event.
- **Durability of Device:** Some children play roughly, and since this device was meant to be used by many children, the durability of the device was an important design goal. The device was still functional after the children at Vernon Hill Elementary were finished using it, however the durability could be improved. Stronger materials could be used so that the forces have less chance of breaking the components. Springs could be incorporated to provide a more durable structure. A different method of attaching the air pumps would also be beneficial so that they do not come apart from shear forces but still be replaceable if needed.

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Appendices

Appendix A: Setup Arduino and Load Cells to MATLAB

```
% HX711 pins
HX711_dout = 6; % mcu > HX711 dout pin
HX711_sck = 7; % mcu > HX711 sck pin
% HX711 constructor
LoadCell = HX711_ADC(HX711_dout, HX711_sck);
calVal_calVal_eepromAdress = 0;
t = 0;
% Setup
fprintf('Starting...\n');
% Calibration value
calibrationValue = 696.0; % uncomment this if you want to set this value
in the sketch
% Uncomment the following lines if you want to fetch calibration value
from EEPROM
if isequal(exist('EEPROM', 'class'), 8) % Check if EEPROM class exists
   calibrationValue = EEPROM.read(calVal_calVal_eepromAdress);
end
LoadCell.begin();
% LoadCell.setReverseOutput();
stabilizingtime = 2000; % tare precision can be improved by adding a few
seconds of stabilizing time
tare = true; % set this to false if you don't want tare to be performed in
the next step
LoadCell.start(stabilizingtime, tare);
if LoadCell.getTareTimeoutFlag()
   fprintf('Timeout, check MCU>HX711 wiring and pin designations\n');
else
   LoadCell.setCalFactor(calibrationValue); % set calibration factor
(float)
   fprintf('Startup is complete\n');
end
while ~LoadCell.update()
end
fprintf('Calibration value: %f\n', LoadCell.getCalFactor());
fprintf('HX711 measured conversion time ms: %f\n',
LoadCell.getConversionTime());
fprintf('HX711 measured sampling rate HZ: %f\n', LoadCell.getSPS());
fprintf('HX711 measured settling time ms: %f\n',
LoadCell.getSettlingTime());
fprintf('Note that the settling time may increase significantly if you use
delay() in your sketch!\n');
```

```
if LoadCell.getSPS() < 7
   fprintf('!!Sampling rate is lower than specification, check MCU>HX711
wiring and pin designations\n');
elseif LoadCell.getSPS() > 100
   fprintf('!!Sampling rate is higher than specification, check MCU>HX711
wiring and pin designations\n');
end
% Loop
newDataReady = 0;
serialPrintInterval = 500; % increase value to slow down serial print
activity
while true
   % check for new data/start next conversion:
   if LoadCell.update()
       newDataReady = true;
   end
   % get smoothed value from the dataset:
   if newDataReady
       if millis() > t + serialPrintInterval
           i = LoadCell.getData();
           fprintf('Load_cell output val: %f\n', i);
           newDataReady = 0;
           t = millis();
       end
   end
   % receive command from serial terminal, send 't' to initiate tare
operation:
   if Serial.available() > 0
       inByte = Serial.read();
       if inByte == 't'
           LoadCell.tareNoDelay();
       end
   end
   % check if last tare operation is complete:
   if LoadCell.getTareStatus() == true
       fprintf('Tare complete\n');
   end
end
```

Appendix B: Function to Calibrate Force Plate Data

```
 %% Calibration (This should be done only once)
    cal_button = 'D12';
 % Set the button pin as input
    configurePin(a, cal_button, 'DigitalInput');
 pause(1)
 cal_button_status = readDigitalPin(a,cal_button);
 %% Place 10Lb plate for calibration
    disp('Place known weight')
 pause(2)
    disp('Press Button to Calibrate')
while cal_button_status == 0
 cal_button_status = readDigitalPin(a,cal_button);
     if cal_button_status == 1
 % Change second number to known weight in grams
 cal = calibration(800, 71667);
 break
  else
     end
end
 %% Take off 10Lb plate for taring
    disp('Take off known weight')
 pause(2)
 cal_button_status = readDigitalPin(a,cal_button);
      % Prompt user to proceed to tare
 disp('Press Button to Tare')
    while cal_button_status == 0
  cal_button_status = readDigitalPin(a,cal_button);
      if cal_button_status == 1
 disp('Please wait...')
 tare(cal, LoadCell);
 break
   else
      end
 end
 %% Put back 10Lb plate for scaling
    disp('Place known weight again')
 cal_button_status = readDigitalPin(a,cal_button);
 pause(2)
     % Prompt user to proceed to scaling
 disp('Press Button to Scale')
    while cal_button_status == 0
  cal_button_status = readDigitalPin(a,cal_button);
     if readDigitalPin(a, cal_button) == 1
 disp('Please wait...')
 scale(cal, LoadCell);
```

```
    disp('Calibration complete!')
    pause(1)
    break
     else

        end
       end

end
```

Appendix C: Function to Run Force vs Time Analysis for Jump

```
% Name: force_vs_time_analysis
% Inputs:
%    cal - calibration value from the calibration function
%    LoadCell - recognize the loadcells and call their function
% Outputs:
%    Figure 1 - Force-time graph
%    Figure 2 - Key Statistics
%
% Created by: Biomechanics Demo MQP Team (2023-24)
% Authors: Daniela Galvan Sanchez, Chris Nguyen, Cara Yorina
%
% Description: Initiate jump trials while providing statistics and graphs
% of each trial
%
% After pressing the green button, the code should take the user here
where
% the jump trials are initiated. Jump trials are 4.5 seconds long with a
% sampling rate of 50 Hz
   time = 0:0.02:4.5;  % Vectorized time calculation (Starts at 0s and
ends at 4.5s at 0.2s intervals)

   % Initialize the matrix to store time and force readings
   forceMatrix = zeros(2, length(time));

   % Iterate over time and acquire data
   for i = 1:226
       % Acquire data
       mass = get_weight(cal, LoadCell);
       forceMatrix(2, i) = (mass / 1000) * 9.81;
       forceMatrix(1, i) = time(i);
       % Plot data continuously
       plot(forceMatrix(1, :), forceMatrix(2, :));
       drawnow; % Update plot
      end

       xlabel('Time (s)');
       ylabel('Force (N)');
       title('Force vs Time', 'FontSize', 18);
       grid on;
  % Find any outliers/noise that may interfere with calculations and
   % replace with previous known value
   if forceMatrix(2,:) < -200
       index = find(forceMatrix(2,:) < -200, 1, 'first');
       forceMatrix(2,index) = forceMatrix(2,index-1);
   else
```

```
   end
%% Flight Time Calculations
   % Set force threshold to 50 Newtons to initiate flight time
   threshold = 50;
   % Use logical indexing to find time values above threshold
   ind1 = find(forceMatrix(2,:) < threshold, 1, 'first');
   ind2 = find(forceMatrix(2,:) < threshold, 1, 'last');

   % Check if ind1 and ind2 are not empty
 if ~isempty(ind1) && ~isempty(ind2)
       % Get corresponding time values
       time1 = forceMatrix(1, ind1);
       time2 = forceMatrix(1, ind2);

       % Calculate the change in time
       timeDifference = time2 - time1;
       flight_height = ((timeDifference^2*9.81)/8) * 39.37;
   else
       fprintf('No values below the threshold found.\n');
       return
 end
%% Impulse-Momentum Theorem
% Get initial reading of bodyweight
bodyweight = forceMatrix(2,1);
% Subtract bodyweight to shift x axis
forceMatrix(2, :) = (forceMatrix(2, :) - bodyweight);
% Find the peaks of jump and landing impulse
[peak,idx1] = max(forceMatrix(2,1:ind1));
[peak,idx2] = max(forceMatrix(2,ind2:end));
idx2 = idx2 - 1 + ind2;
% Find area under new curve using total impulse - flight impulse
impulse1 = trapz(forceMatrix(1,1:end),forceMatrix(2,1:end)); % Total
impulse
impulse2 = trapz(forceMatrix(1,idx1:idx2),forceMatrix(2,idx1:idx2)); %
Flight impulse
impulse = impulse1-impulse2;
% Find when the force dips below bodyweight to initiate power time and
% subtract that from peak time
index1 = find(forceMatrix(2,:) < -20, 1, 'first');
power_time = forceMatrix(1,idx1)-forceMatrix(1,index1);
% Calculate velocity = impulse/mass
imp_velocity = impulse/(bodyweight/9.81);
% Calculate height = velocity^2/2g
imp_height = imp_velocity^2/(2*9.81);
imp_height = imp_height * 39.37;
% Calculate Power
power = impulse ./ (power_time)*imp_velocity;
% Calculate force produced during takeoff
```

```
force = impulse ./ power_time;
%% Displaying results
f = figure;
f.Position(3:4) = [2000 1000];
str1=sprintf('Takeoff Speed: %.0f m/s',imp_velocity);
botleftrh1=annotation('textbox', [.01 .01 .48
.33],'string',str1,'BackgroundColor',[0.99,0.56,0.56],'HorizontalAlignment
','center','VerticalAlignment','middle','FontWeight','bold');
sz1 = botleftrh1.FontSize;
botleftrh1.FontSize = 76;
str2=sprintf('Jump Height: %.0f inches',flight_height);
centerrh2=annotation('textbox', [.15 .34 .70
.33],'string',str2,'BackgroundColor',[1,0.93,0.03],'HorizontalAlignment','
center','VerticalAlignment','middle','FontWeight','bold');
sz2 = centerrh2.FontSize;
centerrh2.FontSize = 80;
str3=sprintf('Power: %.0f Watts',power);
botrightrh3=annotation('textbox', [.5 .01 .49
.33],'string',str3,'BackgroundColor',[0.49,0.83,0.24],'HorizontalAlignment
','center','VerticalAlignment','middle','FontWeight','bold');
sz3 = botrightrh3.FontSize;
botrightrh3.FontSize = 80;
str4=sprintf('Flight Time: %.2f s',timeDifference);
topleftrh4=annotation('textbox', [.01 .67 .48
.33],'string',str4,'BackgroundColor',[0.32,0.73,1],'HorizontalAlignment','
center','VerticalAlignment','middle','FontWeight','bold');
sz4 = topleftrh4.FontSize;
topleftrh4.FontSize = 76;
str5 = sprintf('Force: %.0f N',force);
toprightrh5=annotation('textbox', [.5 .67 .49
.33],'string',str5,'BackgroundColor',[0.88,0.7,1],'HorizontalAlignment','c
enter','VerticalAlignment','middle','FontWeight','bold');
sz5 = toprightrh5.FontSize;
toprightrh5.FontSize = 86;
disp('Force vs time analysis complete!')
end
```

Appendix D: Function For Calibration and Force vs. Time Analysis

Using Button Interface

```
function buttonForceAnalysisButtonPress()
% Name: buttonForceAnalysisButtonPress
% Inputs:
%    None
% Outputs:
%    None
%
% Created by: Biomechanics Demo MQP Team (2023-24)
% Authors: Daniela Galvan Sanchez, Chris Nguyen, Cara Yorina
%
% Description: Allow users to press external buttons to initiate
%              calibration and jumping trials
%
% First, connect the Arduino to USB port
% NOTE: You need to have Arduino IDE pre-installed onto the computer and
% have the Adafruit/Neopixel library installed for LEDs to work. For more
% information go to
%
https://www.mathworks.com/matlabcentral/fileexchange/72707-neopixel-add-on
-library-for-arduino
% and follow the instructions to install the add-on.
   clear
   clc
   close all
   addpath ('Adv_UNO_HX711_Matlab-master/');
   listArduinoLibraries;
   % Most likely you will have to change the first parameter (which is the
   % port name)
   a = arduino
('/dev/cu.usbmodem1101','Uno','libraries',{'advancedHX711/advanced_HX711',
'Adafruit/NeoPixel'});
   LoadCell = addon (a,'advancedHX711/advanced_HX711','Pins',{'D4','D5'});
   read_HX711(LoadCell);

   % Define pin for the button. Modify this according to your setup
   start_button = 'D9';
      cal_button = 'D12';
   % Define LED strips
   nstrip1 = addon(a, 'Adafruit/NeoPixel', 'D7', 120, 'NeoPixelType',
'GRB');
   % Initialize strip to be flashing red, yellow, green, red
   writeColor(nstrip1, 1:120, 'red');
```

```
  pause(1)
  writeColor(nstrip1, 1:120, 'off');
  writeColor(nstrip1, 1:120, 'yellow');
  pause(1)
  writeColor(nstrip1, 1:120, 'off');
  writeColor(nstrip1, 1:120, 'green');
  pause(1)
  writeColor(nstrip1, 1:120, 'off');
  writeColor(nstrip1, 1:120, 'red')

  % Set the button pins as input and initialize the status for both
  configurePin(a, start_button, 'DigitalInput');
     configurePin(a, cal_button, 'DigitalInput');
  cal_button_status = readDigitalPin(a, cal_button);
  start_button_status = readDigitalPin(a, start_button);
     %% Calibration loop until button press
  fprintf('Press the button to start calibration...\n');
     while cal_button_status == 0
      cal_button_status = readDigitalPin(a, cal_button);
if cal_button_status == 1

  % Button pressed, start force vs time analysis
  fprintf('Button pressed. Starting calibration...\n');
  for i = 2:120
  writeColor(nstrip1, i-1, 'off', i, 'yellow');
  end
  for i = 1:119
      writeColor(nstrip1, 120-i, 'yellow')
  end
     cal = calibration_function(a, LoadCell);
  writeColor(nstrip1, 1:120, 'green');
  pause(0.5)
  writeColor(nstrip1, 1:120, 'off');
  writeColor(nstrip1, 1:120, 'green');
  pause(0.5)
  writeColor(nstrip1, 1:120, 'off');
  writeColor(nstrip1, 1:120, 'green');
  break
else
end
     end

 %% Read data loop until button press
  fprintf('Press the button to start force vs time analysis...\n');
     while start_button_status == 0
      while 1
      start_button_status = readDigitalPin(a, start_button);
if start_button_status == 1
```

```
% Button pressed, start force vs time analysis
   fprintf('Button pressed. Starting force vs time analysis...\n');
   close all
   writeColor(nstrip1, 1:120, 'off');
   b = 1;
   for i = 1:6
   writeColor(nstrip1, b:b+19, 'green');
   pause(0.25);   % pause for 250 ms
   b = b+20;
   end
      force_vs_time_analysis(cal, LoadCell);
 else
 end
         end
   end
end
```

Appendix E: Consent Form Flyer

Consent Form

Awesome Benefits

- Experience engaging challenges with the WPI STEM Center, making learning biomechanics fun!
- Gain valuable knowledge and understanding of biomechanics concepts through our interactive activities.

Risks and Safety Information

- Please be aware that unsteady landings while using the platform may pose a risk of injury. To ensure stability, we have added feet placement markings.
- For your safety, please wear closed-toe shoes and flexible clothing. Loose accessories may cause accidents.
- If you have a lower-leg injury, we recommend refraining from using the platform to prevent further injury.

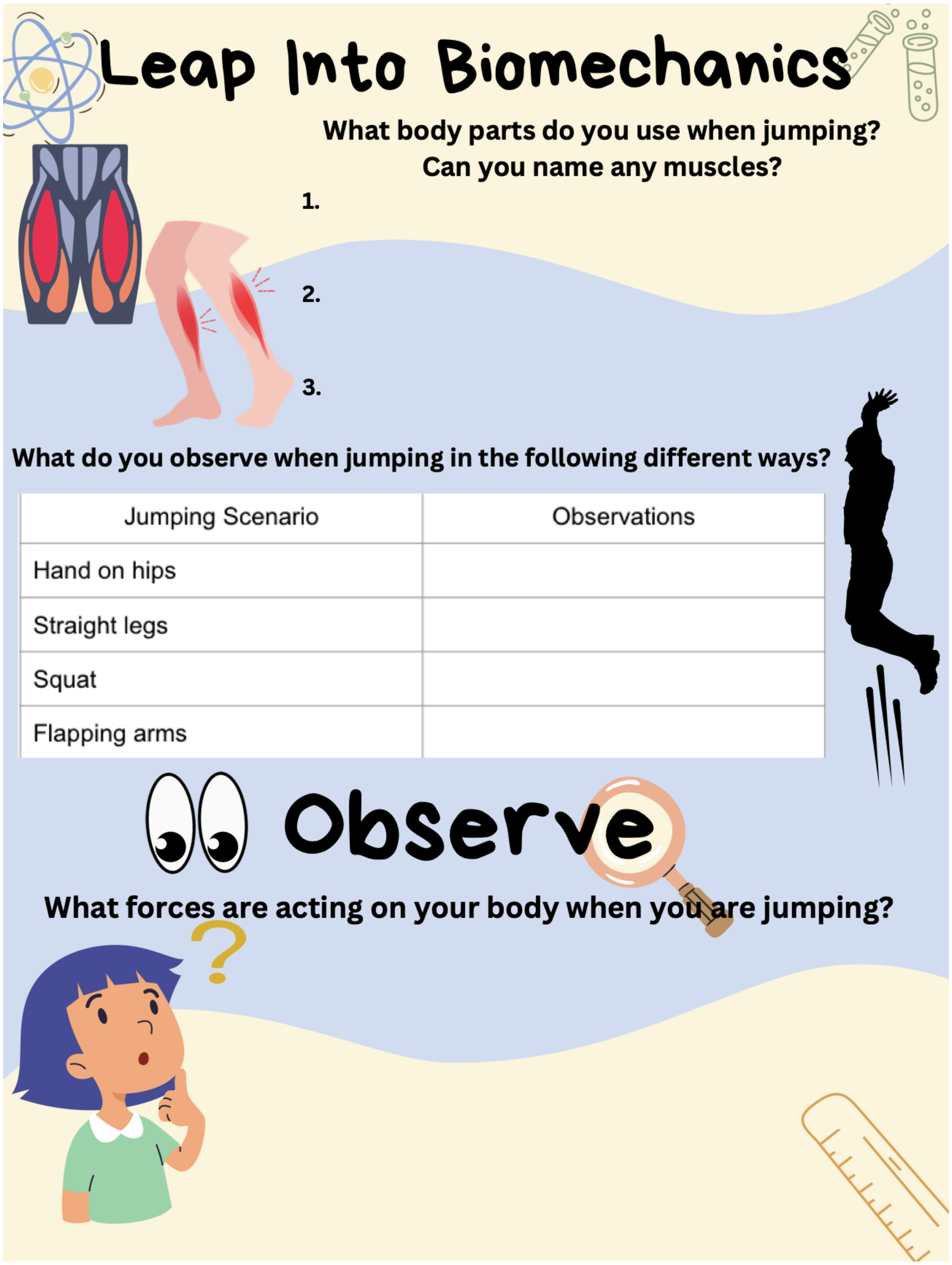
Thank you for your cooperation and understanding. Your kid's safety is our priority.

I, ________________[Parent/Guardian Name], give permission for my child, ________________[Participant's Name], to participate in the interactive jump platform activity. I understand the benefits include improved stability, engaging challenges, and learning about biomechanics. I agree to the safety guidelines provided by the organizers.

Parent/Guardian Signature: ________________
Date: ________________

For more information about this research or about the rights of research participants, or in case of research-related injury, contact: BME MQP Demo Team (gr-mqpbiomechanicsdemonstrationadvisor@wpi.edu), the IRB Manager (Ruth McKeogh, Tel. (508) 831-6699, Email: irb@wpi.edu), or the Human Protection Administrator (Gabriel Johnson, Tel. 508-831-4989, Email: gjohnson@wpi.edu).

Appendix F: Worksheet Provided to Vernon Hill Elementary Students



Leap Into Biomechanics

What body parts do you use when jumping?
Can you name any muscles?

1.

2.

3.

What do you observe when jumping in the following different ways?

Jumping Scenario	Observations
Hand on hips	
Straight legs	
Squat	
Flapping arms	

Observe

What forces are acting on your body when you are jumping?

Record your jump heights!

Rung Height	Jump Platform

Calculations

Equations

Gravity (g) = 9.81

$$\text{Jump height} = \frac{\text{Velocity}^2}{2g}$$

Impulse = mass * velocity

If you weigh a mass of 55 kg and you jumped a height of 0.30 meters calculate the impulse.

Given that the rungs are 0.75 inches apart, what would be your rung jump height if you hit 16 rungs?