Short Video Projects on Physics Education:

The Physics of Weightlifting

Worcester Polytechnic Institute, IQP

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Abstract:

In our interactive qualifying project (IQP), our goal was to create short videos that were designed for physics education. These videos will help people understand general physics in a fun and interactive way. They are meant for any students who do not have the resources needed to learn about physics in a classroom. The videos can help them educate themselves on physics through the concepts in them.

The videos were designed using research and the best practices to ensure student understanding, and correct physics concepts. Two short videos were made, which emphasized various concepts valued within an introductory physics course. The first video on the bench press focuses on the acceleration due to gravity, force vectors, as well as work done during the movement. A vector is a mathematical variable that has both magnitude and direction. Vectors are commonly used in physics and engineering to show a quantity that has these two characteristics, such as displacement, velocity, acceleration, and force. The second video details the back squat movement and focuses on the center of mass, kinetic and potential energy, and inertia. The goal of our project is to use these videos to teach various beginner level physics concepts to those who are interested in learning about these topics and how physics relates to good form in lifting.

Acknowledgements:

Sean and I would like to take a moment to thank Professor Kafle and Professor Noviello for all their help to make this project possible. We really appreciate all their hard work in helping us get through our work. We would like to thank them for their guidance and contributions not only in our videos but in our writing and the steps we need to take to sufficiently complete both.

We are very appreciative to have had amazing professors, and without their help throughout this process I really don't know how we would've gotten throughout. Overall, we are thankful WPI was able to give us the resources needed to complete our projects and are so thankful to have had Professor Kafle and Noviello guide us through this project.

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1 Introduction:

The focus of this IQP was to create short videos about weightlifting that explain the physics that occurs in the video to help assist in the education of students in schools where resources are limited to learn about basic physics concepts. This project focuses on the physics of weightlifting and the videos are published on YouTube so that anyone of all ages around the world can access them and our report to help teach them physics. The two advisors of this project are Professors Kafle and Noviello who helped confirm all physics that were identified in the exercise and videos.

2 Background:

All lifting starts with gravity, gravity is an attractive force between two objects with some masses and separated by a certain distance. For example, when we take the bar off the rack for a squat, Earth is applying a force (force of gravity) to the barbell and us as the lifter, and it's pulling both the bar and lifter straight towards the floor. Force is an important topic behind weightlifting. From Newton's second law of motion, the net force on an object with mass m and moving with an acceleration **a** is given by $\vec{F} = m\vec{a}$

Force is a push or a pull that can create a change in the velocity of an object that the force is being applied. When the force of gravity pulls down on the bar, a lifter must produce a force up against the bar to keep it from accelerating downward toward the floor. If the lifter applies a force on the bar equal to its weight, the bar will remain at rest if initially at rest.

However, to move the bar upward at a constant velocity, the lifter must apply a force slightly greater than its weight to accelerate it, and then adjust to a force equal to its weight to maintain that constant velocity. If the lifter creates a force much greater than the weight of the bar, it will accelerate upward instead of moving at a constant velocity. Overall, weightlifting captivates how the interplay of forces, motions, and energy play a role in the correlation between physics and exercising.

3 Research:

3.1 Bench press:

The barbell bench press is done with the body lying in a flat position (on your back) with the upper half of the body parallel to the earth's surface (on a flat bench) as seen in Figure 1. Because the force of gravity works in a straight line (pushing downwards), we know that when we move the barbell, we must move it against the force of gravity (upwards). (1) Depending on how the body is positioned (parallel to the ground), we can determine how the lifter will use their muscles to produce the upward force against the force of gravity and the inertia of the bar. The definition of inertia is Newton's first law, and it states that an object at rest or in motion will continue to do so unless acted upon by a force as seen in Figure 2.

Figure 1: Lifter at the top of the bench press exercise in supine position.

The velocity of the barbell changes at each part of the lift. Initially, the barbell is at rest. The barbell is lowered to the chest at a constant velocity, then it decelerates and comes to rest

above the chest due to the muscles and forces they create stopping the barbell. When the bar is pushed upwards to return to the top of the exercise, it accelerates again to reach a constant velocity before finishing the movement. (2)

Many powerlifters will use an exaggerated back arch when they perform their bench press. Though arching your back is done, in part, to protect the shoulders and create more stability in doing so, many non-powerlifters view the higher arches as cheating. It may seem as though it is a cheat, but it is legal in powerlifting. The benefit of the exaggerated back arch is the decreased range of motion. (5) Based on our prior knowledge of energy and work,

Work done (w)= Force (f) x Distance traveled in direction of force (d):

$$w = fd$$

With a decreased distance the bar does not have to travel as far from the chest to the top of the movement, so it requires less work. The arch is a way to push more weight using the same amount of energy since there is less distance to move. Wrist stacking is a technique in benching where the hand and wrists are directly lined up above the forearm instead of bending backward. In simpler terms, it would look like the lifter is punching the ceiling. Its name describes it well. Wrist stacking is crucial in the bench press for a few reasons. Aside from stability and protecting the wrists from strain, wrist stacking is preventative to additional torque applied to the person. With the wrist stacked directly above the forearms, the bar will be moving in a straight path along the axis of rotation, whereas if the bar is not directly in line with the axis of rotation (the wrist).

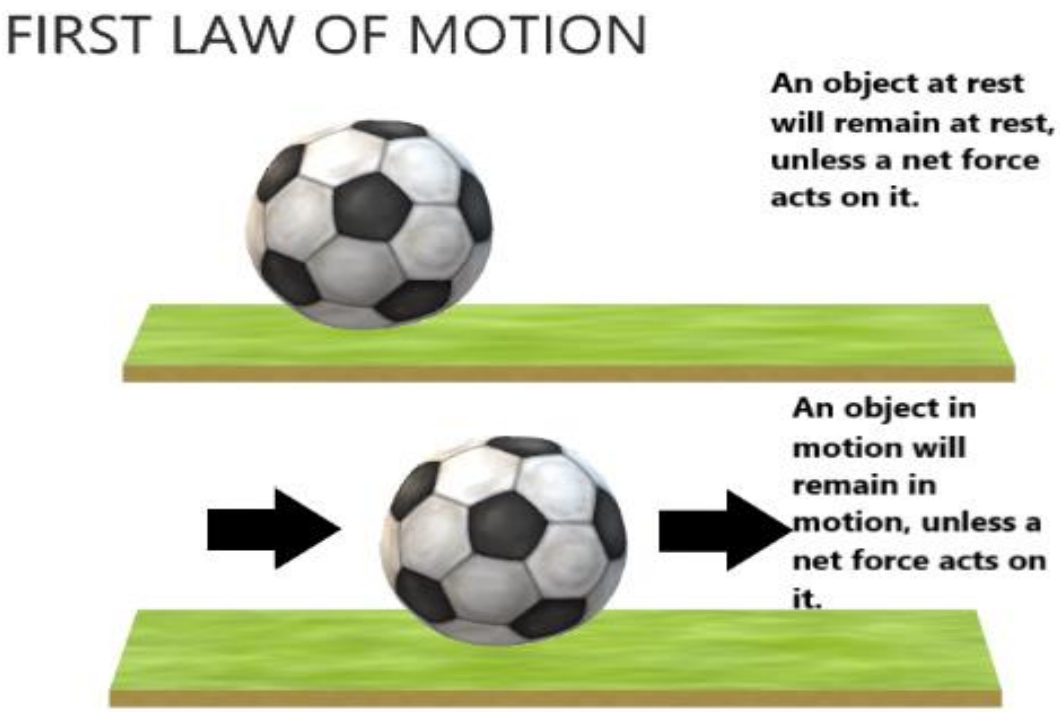

Figure 2: Newtons First Law of Motion/Inertia (6)

3.2 Back squat:

Regardless of either high bar or low bar squat, the patterns of force, center of mass, and energy are the same. Initially, the bar is at rest at the top of the movement, with gravitational potential energy. Then, as the bar descends at a constant rate the due to the force applied by the lifter and the force of gravity in the downward direction. (4) At the bottom of the squat movement, the thighs, glutes, and hips apply force upwards, driving the body back to its initial position at the top.

This movement creates inertia in motion for the barbell meaning that the barbell resists changes to its motion, so once it is moving, it continues moving smoothly and this resistance is

felt throughout the entire exercise. In looking at the low bar squat with the axis of rotation being the hip, we see that it makes sense for there to be more hip flexion and less knee flexion. The weight is distributed closer to the hip than the knee, simply put, making it easier for the hips to take over in the squat movement.

While the force of the barbell and plates does not change, its position changes relation to where you are in the movement. When the bar and its center of mass are more "centered" on the body from the side, and the weight move straight up and down the lift is safer and easier on the joints and body this is why knee flexion is most prominent in the high bar squat as seen in Figure 2. (3)

To calculate the center of mass of a simple system in one dimension (along *x* direction), we can use the following equation:

$$\mathrm{COM}(x) = \frac{m_1 x_1 + m_2 x_2 + \cdots}{m_1 + m_2 + \cdots},$$

where *m*'s are the masses of point objects and *x*'s are the distances of those objects from the origin. We can similarly calculate the center of mass coordinates in other directions.

When performing the back squat, the lifter and the weights have one center of mass (COM) this is the balance point for the lift. To properly perform the lift, you need to keep your COM in a straight vertical line throughout it. To maintain that line, you need to start with a good stable stance feet shoulder width apart and then bend at the knees moving down without bending your back so you can maintain your balance and COM. (3) Holding the barbell higher and less backward will

decrease the hip hinge and bending over of the lower back. Thus, it is necessary that the knees rotate more to reach the needed depth in a squat.

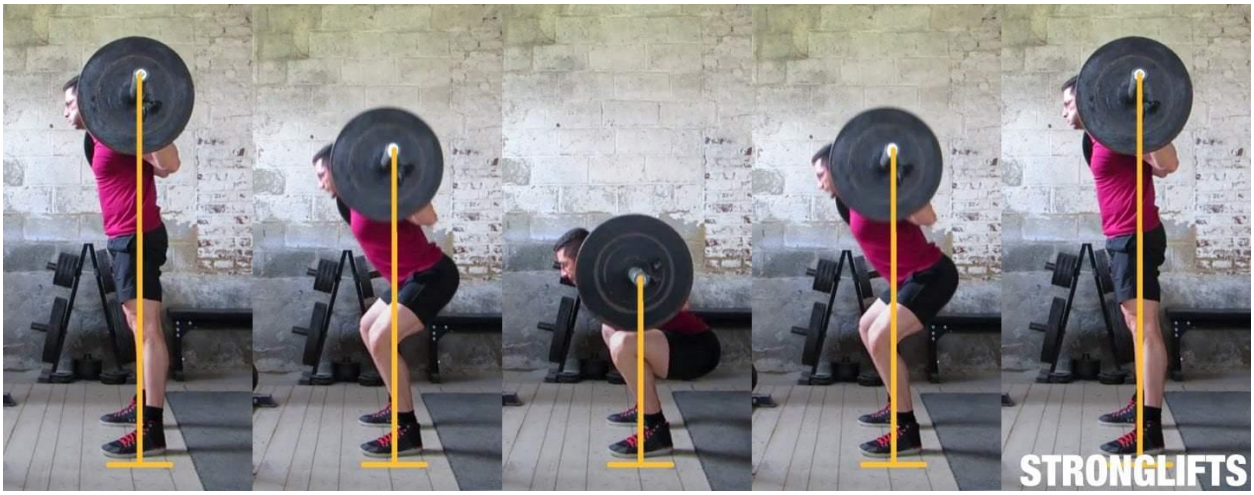

Figure 3: Demonstration of the Center of mass staying in a straight up and down linear motion throughout the lift. (3)

4 Methodology:

The first step of the project was to research physics concepts that could be used for two videos on the bench press and the back squat. I recommend looking at all the past short video projects done at WPI with Professors Noviello and Kafle before starting this project, an example of one of these projects is reference 8.

We used physics concepts that anyone can understand for our lift exercises to make it for anyone that wanted to watch and learn. The physics concepts used for the bench press were Newton's laws of motion, vectors, forces, and work for the bench press. The back squat video focused on center of mass, kinetic energy, potential energy and inertia.

Two separate videos of the bench press and back squat were filmed on an iPhone before creating animations on an IOS app named Animate that went into the videos. Looking back on the project I would recommend not doing animations as they are difficult to make look good and take a very long time. Instead of the animations use the time filming other in person videos that can explain the physics concepts better. After all videos clips were gathered, they were edited together on IMOVIE and Final Cut Pro to create two short videos that can educate anyone on the general physics concepts previously mentioned as seen in Figure 4.

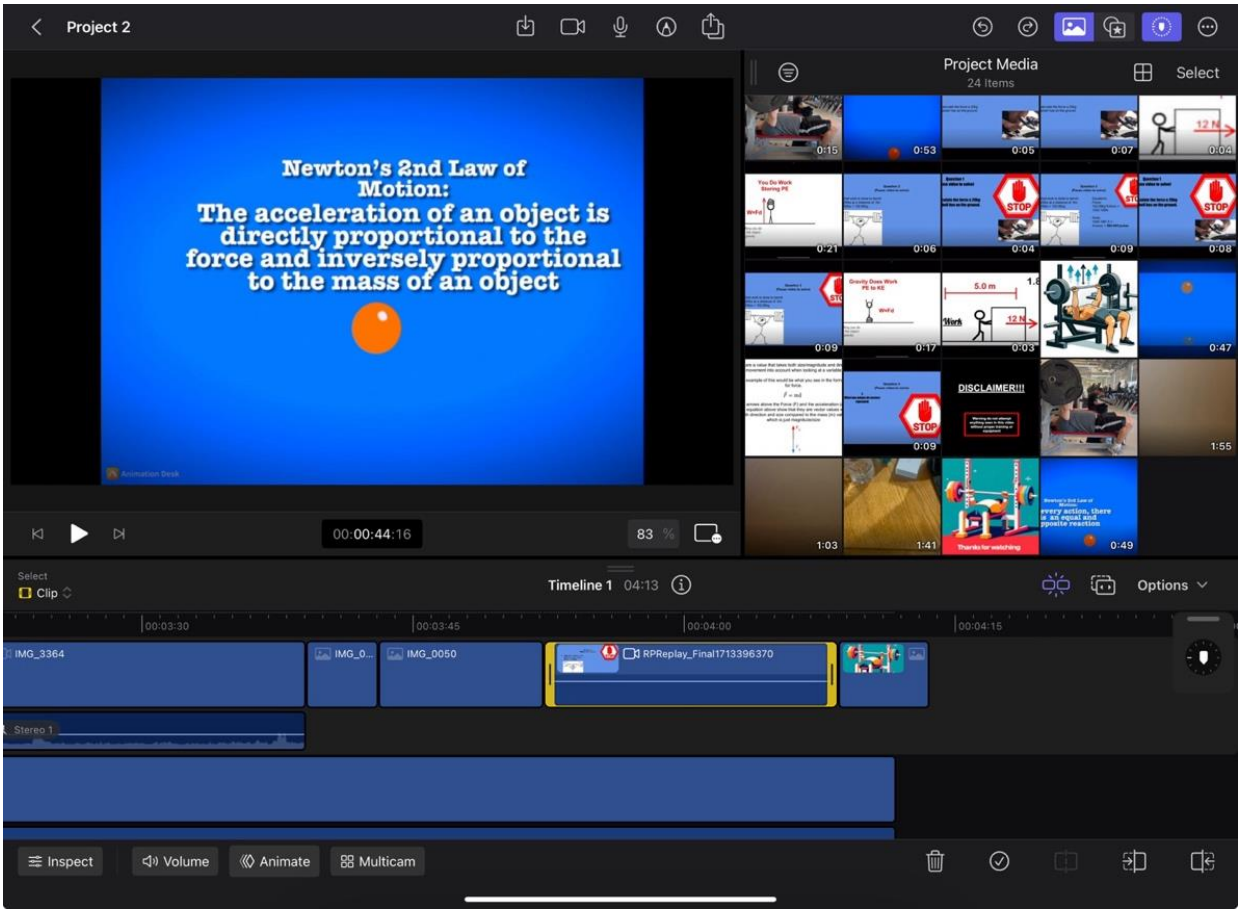

Figure 4: Final Cut Pro Editing Software

There were a few learning curves when editing the videos together that took longer than expected to finish like the animations and the voiceover. The main issues we ran into when editing was linking up the voiceover audio and creating the animations. This was because of the time it took to learn how to use the software and to make the animations. For the voiceover problem we fixed it by recording multiple voiceover sections and stringing them together at the end of your editing, we used an iPhone for our microphone.

5 Discussion:

There were many key takeaways we gained while completing this project like what we would do differently if we did this again, and the experience gained researching both physics and weightlifting. We were able to learn a lot and refresh ourselves about physics while completing the project. From the beginning of the project, we made a plan to get everything done on time which was a great idea, but some different things could have been prioritized over others. We had some struggles with our animation, and looking back, we should have just filmed more clips with the iPhone to help shorten that process. That said we came in with the goal of producing high-quality videos that can be educational for all viewers, and I believe we accomplished this goal. There was ultimately some setback with timing and with editing the videos particularly in the voice over, and animations, but we were able to overcome these challenges.

No funding was needed for these videos, and everything was shot within the WPI recreational facility and edited on a third-party IOS app. All videos were taken on an iPhone and created in IMOVIE and another software Final Cut Pro as well as the voice over. In the end, we worked tirelessly on creating educational videos that are interactive and fun and were able to do so in connection with a sport we love. I truly believe that we not only encourage learning physics, but we also encourage some to begin their fitness journey. We could not have completed this project without the help from Professor Kafle and Professor Noviello, they helped us tremendously on this journey.

6 Conclusion:

Throughout this project we not only taught our viewers, but we gained knowledge and experience ourselves. We had downs with this project and setbacks, but ultimately, we persevered through these challenges to produce high-quality work. We were able to achieve our goal and expand beyond our own expectations.

We hope that many can find takeaways from our work and gain an interest not only in physics but in the world of weightlifting. Our purpose was to create fun, interactive, and educational videos about the physics of weightlifting with the intended audience to be students who do not have the resources to learn about introductory physics and simply anyone who is willing to learn.

Professor Kafle and Professor Noviello helped to achieve the goal of providing these educational videos for all interested parties. We are happy with the result of our work, and we all hope that our project will continue to teach and inspire students.

7 Video Transcripts:

7.1 Video 1 Bench Press:

OneDrive WPI Video Link:20240530_211723000_iOS.mov

Scenes, Questions and Concepts discussed in Video:

Title: The Physics Behind Strength Training: Bench Press

Introduction:

- **Scene:** WPI logo and disclaimer.

Concept 1: Newton's Laws

- **Scene:** A photo of Newton and a ball falling while his laws pass by the screen and are explained

Concept 2: Gravity and Force

- **Scene:** A ball falling and talking about the acceleration due to gravity and the number used for it, showing the equation for Newton's 2nd law, and explaining gravity.
- $\vec{F} = m\vec{a}$

Question 1

Pause for a quick quiz - Can you calculate the force a 20kg barbell has on the ground?

Answer = (196N)

Concept 3: Vectors

Scene: Introduction and explanation of vectors

Question 2:

"What two values does a vector represent

Answer = magnitude and direction

Concept 4: Work/Potential and Kinetic energy

- **Scene:** multiple animations for work and a description and explanation of it

$$w = fd$$

Concept 5: Video of performing the bench press and talking about safety and proper form

- **Scene:** A lifter performing the bench press and talking about proper form and the mechanics of it.

Question 3:

What work is done to lift a 225lb barbell .5m 225lb=102.06kg

Answer = 500.094

Text Transcript of Bench Press Video

-The Physics Behind Strength Training and the Bench Press

-The basics of all motion in physics starts with Issac Newton's three Laws of motion

-The first being that an object at rest or in motion will continue to be in motion or at rest until an outside force act on the object Newtons second Law states that the acceleration of an object is directly proportional to the force on the object, and inversely proportional to the mass of the object. Newtons 3rd law of motion states that for every action there is an equal and opposite reaction.

-Diving further into newtons second law, we will need to understand the standard for the acceleration due to gravity on earth, which is 9.8m/s^2. This is because, as said earlier, the acceleration of an object is directly proportional to the force of an object and inversely proportional to the mass of the object better stated as the equation to find Force which is the mass of the object times its acceleration equals the force. Let's do a quick example problem where the mass is 2Kg and the acceleration is the acceleration due to gravity at 9.8m/s^2.
We plug these values into the equation and get the force which is 19.6 Newtons of force is created.

-Now take a second pause in the video and answer this question.
-If you got 196N as your answer you are correct if not maybe rewatch the example.

-Another very important concept in physics is vectors. Vectors represent two values in physics one being the direction of the values and the other being size or magnitude

-When labeling a vector in an equation for physics, you would place an arrow of the variable which shows you it is representing size and direction. As you can see in the equation above Force and Acceleration are vector values, but mass is not because there is no direction on mass but there is when talking about force and acceleration.

-Now Pause the video and answer question 2 What two values do the vectors represent
-If you said vectors represent size and direction then you would be correct.

-Now putting all the previous information together, we can talk about work in physics and weightlifting

-When you lift anything, you do work. Work is found by the equation Force times distance equals work or as stated here on the sides of the Stickfigure w equals F times D . When you lift the object and do work you store potential energy, and then when you drop the object you release that potential energy as kinetic energy of the object, we go further into this in the next video if you are interested.

-But back to work.

-When lifting something, you are working against gravity as said earlier you can find this work by using the force against the object and the displacement or distance the object is moved.

-As you can see from this bench press lift the lifter is working against gravity to push the barbell and weights up a certain distance. To perform this exercise properly and safely, practice the proper form and only use a weight you are comfortable with.
To perform the bench press properly make sure the weight moves straight up and down and that it is in between your sternum and upper chest but never above your shoulder joint as you can see here and in the video.

-Now, using the equation for force and for work, pause the video and solve what work is done to bench 225lbs also known as 102.06Kg a distance of .5m
-If you got a value of 1000.188N for the force and then used that in the equation for work you should have gotten around 500 joules of work

-Thank you for watching. I hope you enjoyed the video.

7.2 Video 2 Back Squat:

OneDrive WPI Video Link: 20240530_204208000_iOS.mov

Scenes, Questions and Concepts discussed in Video:

Title: The Physics Behind Strength Training: Back Squat

Introduction:

- **Scene:** WPI logo and disclaimer

Concept 1: Center of Mass Explanation

- **Scene 1:** photo displaying the squat at all positions, emphasizing the center of Mass of the lifter.

  Scene 2: An example of a Center of mass equation

  Scene 3: Lucas performing the back squat

Question 1:

Find the Center of Mass of the system?

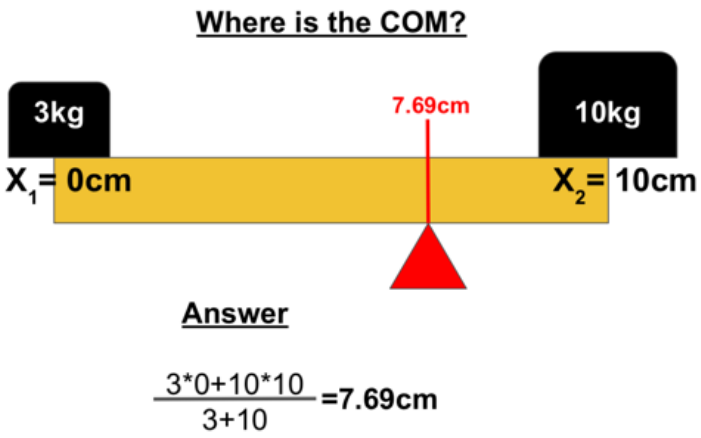

Figure 5: Question 1 and answer to find the center of mass in the back squat video

Concept 2: Kinetic and potential Energy in depth

- Scene 1: Explaining PE\KE
- Scene 2: An example problem for potential energy and explain it in relation to a squat
- Scene 3: An example problem for kinetic energy

Question 2:

A ball is 25 meters off the ground and has a mass of 15Kg what its gravitational potential energy.

PE = mgh

Answer = 3,675 joules

Concept 3: Inertia

- **Scene 1:** An explanation about inertia and Newton's 1st Law.
- **Scene 2:** The motion through the back squat and how it relates to inertia and the safety that comes with it

Question 3:

Imagine someone riding a skateboard down a hill and hit a rock. The skateboard stops but the rider keeps going, why?

Answer:

The Law of inertia, a force stops the board but not the rider.

Text Transcript of Backsquat Video

-The physics behind strength training and the back squat

-The basics of the back squat starts with your center of mass, the center of mass is essentially the balance point of an object, and when squatting, it is very important to keep your center of mass on a consistent line straight up and down so you do not lose your balance and injure yourself

-You can find the center of mass of a system by taking the mass and the distance of the objects on a beam and putting them into this equation. In the equation m is the mass of an object and x is the distance. We can do a quick example with the ruler and weights here. The first weight is 2 kilograms at a distance of 0cm the second weight is 6 kilograms at a distance of 18cm balanced on this ruler

- if you put those numbers into this equation, you can find the center of mass of the ruler with the weights on top filled in it is 2 times 0 plus 6 times 18 divided by 2 plus 6 which makes 108 divided by 8 and it equals 13.5cm which is the center of mass of the system.

- Here the back squat is being performed in a squat rack. This is a good example of perfect form during the squat, bending at the knees and hiding the hip while keeping your back straight and no bend in it. You can also see that the barbell does not move forward or back. It continues a straight path throughout the lift, conserving the center of mass and keeping his balance.

- Now pause the video and find the center of mass if this system if you got 7.69cm you are correct and can continue.

-Now for a deeper look into Kinetic and Potential energy which we briefly touched upon in the bench press video. Kinetic Energy is the energy a moving object or an object in motion has. It can also be said that it is the work needed to accelerate an object from rest to its current speed. The equation to find Kinetic energy is KE equals one half times mass times velocity squared of the object. Potential energy is the energy stored in an object depending on its position which can be referred to as gravitational potential energy which is the energy an object has do to the height from the ground. The equation for potential energy is PE equals mass times the acceleration do to gravity, which we learned in the bench press video is 9.8m/s squared times the height the object is off the ground.

-When talking about potential and kinetic energy in terms of a back squat, the bar has potential energy when it is stationary and at the top of the movement and as the lifter squats down and the bar moves, that potential energy turns into to kinetic energy
Now lets do a quick example problem for potential energy and then kinetic

-If the lifters bar is stationary and it is 1.5m off the ground with a mass of 102.06kg and you use the acceleration due to gravity of 9.8 and you multiply that all together in a equation you get 1,500 joules of potential energy is in the barbell.

For kinetic energy we will imagine a ball rolling down a ramp. The ball is in motion and has a

mass of 102.06 kilograms we also know the velocity is .25m/s Plugging in the mass and velocity to the kinetic energy equation we can find that the ball has 3.9 joules of energy

-Now pause the video and solve question 2's potential energy problem if you got 3,675 joules or around there you are correct

-The final physics concept we will talk about in this video relates back to newtons laws which we discussed in the bench press video. Looking at newtons 1st law or what can also be referred to as the law of inertia An object at rest or in motion will continue to be at rest or in motion until acted upon by another force.

- An easy way to understand inertia is if you are riding a bike and slam on the breaks or hit something that makes your bike stop, the bike stops but the rider continues moving. This is because there is a force on the bike stopping it but not a force on the rider so they stay in motion making the rider fly off the bike.

-During the back squat lift the inertia of the bar can be felt throughout the lift this is why it is very important to move at a slow and consistent pace so that you do not strain your back or muscles during the exercise.

-At the top of your exercise your bar has the highest potential energy, and it has resting inertia which is why if you drop too quickly the bar will not stay on your shoulders and move with you and you will end up hurting yourself with the bar during your decent.

-While descending with the barbell, it has inertia in motion so when you reach the bottom you want to brace and then fight against the force and inertia which if not done properly can cause injury this is why it is important to only use weight you are comfortable using
-You overcome that inertia and the force of the bar and lift the barbell with your glute's thighs and hips back to the top of the motion.

-Pause the video and answer this question

-If you said Newtons 1st law of Inertia is why or because a force stops the board but not the rider you would be correct

-Thank you for watching the video I hope you learned something and enjoyed

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