Physics of Sports

A set of five lesson plans

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Physics of Sports

Lesson 1: Measurements and Accuracy
Teacher's Guide

Connections:

Previous Lesson	Current Lesson	Next Lesson
Units (Length / mass / Time)	Measurements and Accuracy in Sports	Quality Assurance and Physics

Objectives:	• To understand the role of measurements. • To use simple measurement devices to measure and/or estimate physical quantities. • To convert units and compare to established values. • Understand the importance of numerical accuracy and significant digits
Resources required:	• A ping-pong ball • A ruler • A a pair of scissors • Some pieces of cardboard or poster board – 3" x 3" will do • Student's Worksheet Lesson 1
Useful data:	Table dimensions • Length = 274 cm • Width = 152.5 cm • Height = 76 cm • Net height = 15.25 cm The Olympics size ping-pong balls have: • Diameter = 4 cm = 0.04 m • Wall thickness varies but is approximately 0.04 cm.
Video(s):	Start by showing a short video clip where Ping Pong Table Parts (Measurements) and dimensions have been discussed Ask the students to note down all the dimensions mentioned in the video. https://www.youtube.com/watch?v=a60Kl1CVFd4
Mathematics Review:	Ask students if they can recall what is the volume of a sphere? Use that knowledge to calculate the volume of the ball: $V = \frac{4}{3}\pi(\text{radius})^3 \approx (\text{diameter})^3 / 2$ Ask students what is the surface area of a sphere? Use that knowledge to calculate the surface area of the ball $S_A = 4\pi(\text{radius})^2 = \pi(\text{diameter})^2 \approx 3(\text{diameter})^2$

Discussion Questions	The activity starts with some questions: 1. Which system of units is used by the presenter in the video? 2. How is that related to SI system in which the table dimensions are known (see the values given above) 3. Identify the units used (length) and find the conversion factor in the book (1 foot = 0.3048 m). 4. Ask student to convert the units and compare to the values available in this sheet. 5. Provide them a ping-pong ball and ask them to find ways to measure its diameter (for example they can hold the ball between two flat and parallel surfaces and measure the distance between those surfaces). A number of follow-up questions can now be asked to prepare for the next class: 1. What did you learn from the video and later calculations? 2. Why do you think these measurements are important? How are they relevant to the success of the sport? 3. What will happen if you use a table that does not meet the standards? What tests might you use to find out if the table meets the standards? 4. What other factors about the table should be checked? Different characteristics of the table change the physical properties and how the ball will react to it. For example, a very smooth table will have less friction whereas a rough table will have more. Use the student's responses to examine physical properties.
Fun fact	The sport originated in Victorian England, where it was played among the upper-class as an after-dinner parlor game. It had several different names, including 'whiff-whaff', and it has been suggested that makeshift versions of the game were developed by British military officers in India or South Africa, who brought it back with them. A row of books was stood up along the center of the table as a net, two more books served as rackets and were used to continuously hit a golf-ball. https://en.wikipedia.org/wiki/Table_tennis

Student's Worksheet

Lesson 1

Lesson Topic: Units and Measurements

Objective:

In this activity you'll learn the importance of making correct measurements and conversion of units.

Work:

Note down table dimensions discussed in the video:

- Length = _____________
- Width = _____________
- Height = _____________
- Net height = _____________

Using the conversion factor of 1 foot = 0.3048 m, rewrite table dimensions in m and cm

- Length = ________m = ________ cm
- Width = ________m = ________ cm
- Height = ________m = ________ cm
- Net height = ________m = ________ cm

Think of a way to measure the diameter of the ball. Using the method you have devised, find the diameter of the ball and record the results here:

- Diameter = ________ cm

By using the above value, calculate the volume of the ball:

$$V = \frac{4}{3}\pi(\text{radius})^3 \approx (\text{diameter})^3 / 2$$ =__________(write correct units of volume)

Calculate the surface of the ball:

$A = 4\pi(\text{radius})^2 = \pi(\text{diameter})^2 \approx 3(\text{diameter})^2$ =__________(write correct units of area)

General Discussion and Sources of Error:

1. Compare the values given for the standard Olympic table in cm with those you calculated by converting feet to m and cm. Are the values identical? If not, why not?

2. If you use a conversion factor of 1 foot = 0.30 m, how do your values compare to the Olympic values. Does this change the quality of your measurement? Why or why not?

3. When calculating table size, how did you decide the number of significant digits and the unit of measurement to use in this application? Why?

4. Compare the diameter of the ball you have just measured to the standard diameter given. Is your measured value larger, smaller, or just right? If your measurement is not exact, what might explain the difference?

5. Assuming the ball was made under room conditions, what do you expect to be the air pressure inside the ball? The same as atmospheric pressure, more or less?

Physics of Sports

Lesson 2: Quality Assurance and Physics
Teacher's Guide

Connections:

Previous Lesson	Current Lesson	Next Lesson
Measurements and Accuracy	Quality Assurance	Kinematic Variables

Objectives:	• To understand the concept of quality assurance • To connect physics concepts to the quality assurance process
Resources required:	• A table-tennis ball and table or a writing desk • A ruler • The stencil provided with the activity • A pair of scissors • A pencil or marker • Student's Worksheet Lesson 2
Useful data:	Table dimensions • Length = 274 cm • Width = 152.5 cm • Height = 76 cm • Net height = 15.25 cm The Olympics size ping-pong balls have: • Diameter = 4 cm = 0.04 m • Wall thickness varies but is approximately 0.04 cm.
Video(s):	Start by showing a short video clip where a sports disaster is clearly a manifestation of poor quality: https://youtu.be/gkKlr7YOlig
Discussion Questions	The activity starts with some questions: 1. What do you understand by the word: "Quality Assurance" (sometimes called QA) 2. Why do you think QA matters? 3. Which parts of the table-tennis game do you think need a quality control (table surface, dimensions, wood, net size, ball size, ball material, etc.) 4. Suggest tools to measure some of these quantities (meter stick, Vernier, weigh balance, etc.) A number of follow-up questions can now be asked to prepare for the next class: 1. What did you learn from the video and later calculations?

	2. Why do you think these measurements matter? Or are relevant for the physics of sports? 3. What will happen if you use a table which is not up to the standards? How will you find out? 4. What other factors about the table should be checked? (You can remind them that the table material may be important and so is its polish as a very smooth table will have less friction whereas a rough table will have more).
Preparation / Warm-up:	Start with the given stencil and students, working in groups of two, will create the device needed to make the measurements. The stencil is available to the teachers as a separate file to be printed on 8.5x14 paper Tell students that: 1. The standard table yields a uniform bounce of about 23 cm when a standard ball is dropped onto it from a height of 30 cm. 2. Your stencil allows you to measure if the ball bounced 23 cm or more than 27m 3. Repeat the experiment 3 times and record your observations here. 4. If there are balls of other type available (other ping-pong balls, Styrofoam balls, etc.), use them and compare.
Fun fact	You can try to play the game under water: https://www.youtube.com/watch?v=UW2g_Pi1nPM Explore the challenges that are presented in this environment. Suggest ways in which you can improve the quality of game underwater. Note that the crush depth of a ping-pong ball (the depth of water at which a ping-ball collapses due to water pressure outside), is approximately 30 meters.

Student's Worksheet

Lesson 2

Lesson Topic: Quality Assurance in Table Tennis (Ball and Table)

Objectives:

- To understand the concept of quality assurance
- To connect physics concepts to the quality assurance process

Work:

Start with the given stencil working in groups of two. Using the stencil, create the device needed to make the measurements. The stencil is available from the Teacher.

The standard table yields a uniform bounce of about 23 cm when a standard ball is dropped onto it from a height of 30 cm. Repeat the experiment 3 times and record your observations here. Your stencil allows you to measure if the ball bounced 23 cm or more.

First attempt – Did the ball reach 23 cm: Yes / No?

Second attempt – Did the ball reach 23 cm: Yes / No?

Third attempt – Did the ball reach 23 cm: Yes / No?

Now repeat the measurements using a ruler to get a better estimate of the height reached. If there are balls of other type available (other ping-pong balls, Styrofoam balls, etc.), use them and record results here too. (Use a standard ping-pong table for this experiment)

Attempt	Ball 1 (height reached in cm)	Ball 2 (height reached in cm)	Ball 3 (height reached in cm)	Ball 4 (height reached in cm)
1st				
2nd				
3rd				

Graph the class results on chart paper. Observe any trends.

General Discussion and Sources of Error:

1. What did the graph of classroom results reveal? Were the results consistent? What factors might have influenced the results? How could you change your procedure to ensure consistent results?

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2. If your ball bounced more, what can you do to the surface of the desk to reduce the bounciness?

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3. If the ball bounced less, what can you do to increase the bounciness of the table?

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Physics of Sports

Lesson 3: Kinematic Variables
Teacher's Guide

Connections:

Previous Lesson	Current Lesson	Next Lesson
Quality Assurance and Physics	Kinematic Variables	Energy measurements

Objectives:	• To use simple measurement devices to measure or estimate physical quantities known as kinematic variables. • To compare them to the real speeds in an actual sport and compare values.
Resources required:	• A table-tennis ball and table or a writing desk • A ruler • A pencil or marker • Student's Worksheet Lesson 3
Useful data:	• Rotational speed of the ball, *v* = *1.0* m/s (average), • Linear speed of the ball *v*= *12* m/s (linear, at tracking limit or the maximum speed at which you can still see it moving)
Video(s):	Start by showing a short video clip where the game is played at a high speed: https://www.youtube.com/watch?v=46OahVA7GNc
Physics Review:	Five equations describe the five parameters in one-dimensional motion of objects: $x = \bar{v}t$ $x = \bar{v}t$ or $\bar{v} = x / t$
Discussion Questions	The activity starts with some questions: 1. Do you have any idea of the speed of the ball in a real ping-pong game (12 m/s)? 2. The video shows the ball moving from one place to another. What kind of motion does this represent? (linear) Do you think that the ball is moving in any other way? (rotational motion). How can you tell? Does it matter? 4. In 2001 the ITTF regulations were changed to increase the ball diameter from 38 mm to 40 mm. How might this relatively small change have impacted the game? Think from the point of view of player and observer. [Slower game for players, easier for spectators to watch the ball!] Extension: 4. Notice that it takes less than a second to the ball to go from one side of the table to the other. That is also the time the other player has to 'see' the ball, judge its future path, rotation direction, and to decide how best to play. What allows players to make these choices so quickly? 5. Estimate the percentage change in the cross-sectional area of the ball which faces air resistance while going from 38mm to 40 mm in diameter.
Fun fact	Ping-pong balls have been used to salvage sunken boats (with some success)! See: https://www.youtube.com/watch?v=IKKu0DA5lvM

Student's Worksheet

Lesson 3

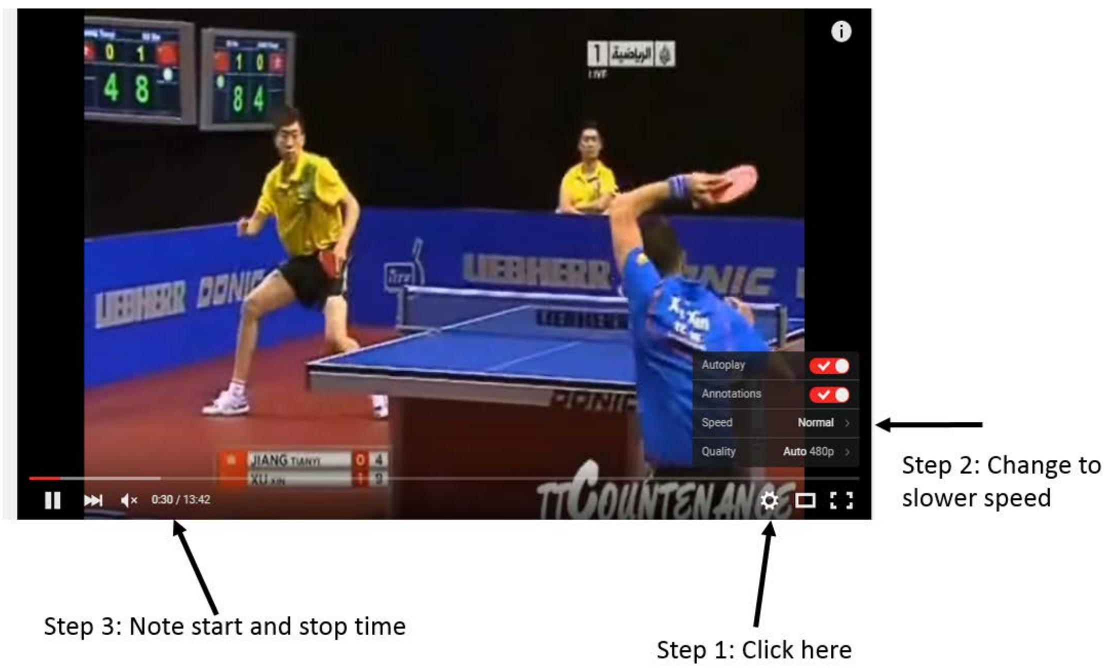
Lesson Topic: Quality Assurance in Table Tennis (Ball and Table)

Objectives:

- To use simple measurement devices to measure or estimate physical quantities known as kinematic variables.
- To compare them to the real speeds in an actual sport and compare values.

Work:

See the video https://www.youtube.com/watch?v=46OahVA7GNc at a slow speed. Here is a screen shot of how you can slow down a YouTube video:



Watch the ball going from one end of the table to the other and estimate the amount of time it takes using the time on the lower bar of the video as shown above.

Data Collection

You now know the length of the table and the amount of time it takes for the ball to travel that distance. Estimate the speed of the ball. Make at least 5 observations of DIFFERENT shots in the above video or elsewhere to calculate the average speed. Complete the following table:

Attempt	Distance travelled (m)	Time taken (sec)	Speed (m/s) (Divide second column with the third)
1			
2			
3			
4			
5			

Average speed = __________________ m/s

General Discussion and Sources of Error:

1. What are the main sources of error in the measurement of distance in this case?

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2. What are the main sources of error in the measurement of time in this case?

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3. The cross-sectional area of the ball facing air resistance can be taken as the area of the circle with the diameter of the ball. Let r1 = 3.8cm (the old standard) and r2 = 4.0 cm (the new ball diameter).

   Area of ball with r1

   The change in the area will then be given by

$$\text{Change in Area} = 4\pi(\text{Larger radius})^2 - 4\pi(\text{Smaller radius})^2$$
$$= \pi(\text{Larger diameter})^2 - \pi(\text{Smaller diameter})^2$$

$$\approx 3[(\text{Larger diameter})^2 - (\text{Smaller diameter})^2]$$
$$= 3[\ (\qquad) \quad - \quad (\qquad)\ ]$$

= ________________

- Hence the percentage change can be calculated as:

$$\text{Percentage change in Area} = \frac{\text{Change in Area}}{\text{Area of 3.8 cm ball}} = \underline{\qquad\qquad\qquad\qquad}$$

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Lesson 4: Energy and its Measurement
Teacher's Guide

Connections:

Previous Lesson	Current Lesson	Next Lesson
Quality Assurance and Physics	Energy and its Measurement	Momentum and its Measurement

Objectives:	• To review and apply the law of conservation of energy • To explain the concept of potential energy and its measurement • To explain the concept of kinetic energy and its measurements • To explore the ways in which energies seem to 'disappear'
Resources required:	• A ruler • The stencil provided with the activity • A pair of scissors • A pencil or marker • Student's Worksheet Lesson 4
Useful data:	Table dimensions • Length = 274 cm • Width = 152.5 cm • Height = 76 cm • Net height = 15.25 cm The Olympics size ping-pong balls have: • Diameter = 4 cm = 0.04 m • Wall thickness vary but is approximately 0.04 cm. • Mass of the ping-pong ball = 2.7 g = 0.0027 Kg • Material used: Celluloid (generally) Speeds: • Rotational speed of the ball, *v* = *1.0* m/s (average), • Linear speed of the ball *v*= *12* m/s (linear, at tracking limit or the maximum speed at which you can still see it moving)
Video(s):	Start by showing a short video clip where the game is played at a high speed: https://www.youtube.com/watch?v=46OahVA7GNc
Physics Review:	Kinetic Energy $=\frac{1}{2}mv^2 == \frac{1}{2}\times mass \times (\text{velocity})^2$ Potential Energy = mgh where $g = 10\text{m/s}^2$ (approximately)
Discussion Questions:	The activity starts with some questions: 1. Do you have any idea of the speed of the ball in a real ping-pong game (12 m/s)? 2. Do you think the ball is rotating while flying? And if yes, can you estimate its rotational speed? (No, not without some special arrangements)

Fun fact	The earliest surviving action game of Tennis on a table is a set made by David Foster, patented in England in 1890. Visit the ITTF site, http://www.ittf.com/museum/history.html to see some historical paintings and photos of the game dating back to 15th century

Student's Worksheet

Lesson 4

Lesson Topic: Energy measurements

Objective:

- To understand and apply the law of conservation of energy
- To explain the concept of Potential energy and its measurement
- To explain the concept of Kinetic energy and its measurements
- To explore the ways in which energies seem to 'disappear'

Work:

A. Potential Energy Measurements

- Remember the activity where you dropped a ball from 30 cm and it bounced back to 23 cm. How much potential energy is lost in this process?

  We know that

  $Energy_{initial} = m\ g\ height_{initial}$

  $Energy_{final} = m\ g\ height_{final}$

  Hence,

  Difference in energies = $m \times g \times (\text{difference in heights}) =$ ____________________

- What is the Potential Energy of the ball when it just touches the surface?

____

____

____

____

- If you let ball keep bouncing up and down, it ultimately stops. What happens to the energy after 3-5 collisions? Where does the energy go?

____

____

____

____

B. Kinetic Energy Measurements

- Roll a ball on the table and measure the distance between any two points you choose.

  Distance = ___________________

- Record the time it takes.

  Time = _____________________

- Using these values calculate average speed:

  Average speed = distance / time _____________________

- What are the units of speed in your calculations above?
- If the units are not m/s, convert them to these units

  Average speed = _____________________ m/s

- Use the known value of mass m to calculate the Kinetic Energy of the ball:

  KE $= \frac{1}{2}mv^2 == \frac{1}{2} \times mass \times (\text{velocity})^2$ _________________________

- Compare the above value with the value of Kinetic Energy at the tracking speed:

  KE $= \frac{1}{2}mv^2 == \frac{1}{2} \times mass \times (\text{velocity})^2$ _________________________

Physics of Sports

Lesson 5: Momentum and its Measurement
Teacher's Guide

Connections:

Previous Lesson	Current Lesson	Next Lesson
Energy and its Measurement	Momentum and its measurement	Aerodynamics of ping-pong balls

Objectives:	• To define linear and angular momentum • To estimate linear and angular momentum • To understand the law of conservation of momentum • To apply these theories to explain the bizarre behavior of the ball in some real situations
Resources required:	• A ruler • A pair of scissors • A pencil or marker • Student's Worksheet Lesson 5
Useful data:	Table dimensions • Length = 274 cm • Width = 152.5 cm • Height = 76 cm • Net height = 15.25 cm The Olympics size ping-pong balls have: • Diameter = 4 cm = 0.04 m • Wall thickness vary but is approximately 0.04 cm. • Mass of the ping-pong ball = 2.7 g = 0.0027 Kg • Material used: Celluloid (generally) Speeds: • Rotational speed of the ball, *v = 1.0* m/s (average), • Linear speed of the ball *v= 12* m/s (linear, at **tracking limit** or the maximum speed at which you can still see it moving)
Video(s):	Start by showing a short video clip where the game is played using a 44mm ball: https://www.youtube.com/watch?v=uphkV6pLwZo
Mathematics Review:	• Linear Momentum = mv • Impulse = Final momentum – initial momentum • Angular Momentum = mvr
Discussion Questions:	The activity starts with some questions: 1. Assume we replace ping-pong balls by tennis balls. What will be the effect of larger mass and volume on the sport?

	2. If you try to play the game using a tennis ball, you feel a strong jerk in the racket. What can you do to reduce it? 3. What is the relationship of momentum and impulse to your design change suggest above? 4. What happens to a ball that starts rolling on the table and then stops – where has the momentum gone? (it was supposed to be conserved) 5. If you slide a ball a certain way on the surface, it moves forward quickly and tries to return. What physics is at play here? See Mr. Beans at the Airport: https://youtu.be/QE6PvNohffc?t=2m6s
Fun fact	Ping-pong diplomacy: China once used ping-pong as a tool to improve its foreign relations. Read more about it here: http://www.allabouttabletennis.com/history-of-table-tennis-ping-pong-diplomacy.html

Student's Worksheet

Lesson 5

Lesson Topic: Momentum measurements

Objective:

- To define linear and angular momentum
- To estimate linear and angular momentum
- To understand the law of conservation of momentum
- To apply these theories to explain the bizarre behavior of the ball in some real situations

Work:

Momentum Measurement

- Linear momentum of the ball during a play. Make multiple measurements of time and distance to estimate the velocity of the ball:

No	Distance (m)	Time (sec)	Speed = Distance / Time (m/s)
1			
2			
3			

Calculate the average speed and find the linear momentum

$p = mv =$ ______________________________ (include units)

- Linear momentum of the ball while it is moving at tracking speed (given earlier):

$p = mv =$ ______________________________ (include units)

- If the ball is rotating around its center, calculate its angular momentum:

Angular Momentum = mvr = mass x velocity x radius = _____________________

- What are the units of angular momentum calculated above? Keep in mind that you will get correct units only if you use mass in kilograms, velocity in m/s and radius in meters. If that was not the case, convert to the correct units and record the value below:

Angular Momentum = _____________________

- Roll a ball on the table or desk until it stops rolling. Where has the angular momentum gone? (momentum is supposed to be conserved)

____

____

Reaction Time Estimation

- If the ball moves with typical speed given earlier, approximately how much time does the player have to decide his next move? _____________ seconds
- List of all the things a player has to do to successfully return the ball to her opponent?

Bonus:

- First watch the Mr. Beans' video, https://www.youtube.com/watch?v=QE6PvNohffc&feature=youtu.be&t=2m6s https://www.youtube.com/watch?v=uphkV6pLwZo
- Why he was unable to move forward on the belt while walking backwards?

- Try to push the ball forward in such a way that the rotational motion returns the ball to you. Observe where you need to apply force to accomplish this. Discuss parallels between this observation and Mr. Bean's video: